CHAPTER 5 Study Approaches and Results

Between 1984 and 1997, the Service conducted the TRFE to assess various flow regimes and other measures necessary to restore and maintain the Trinity River anadromous salmonid fishery resources. The TRFE involved studies that assessed the extent of habitat degradation resulting from hydrological and morphological changes caused by the construction and operation of the TRD, and that evaluated approaches that would reverse the decline of naturally produced anadromous salmonid populations of the Trinity River. These studies, among other things, addressed specific riverine components and included documentation of fisheries habitat within the existing post-TRD channel, evaluated how fluvial geomorphology and associated processes affected the pre- and post-TRD channel, and evaluated the effect of channel rehabilitation efforts on fish habitat. This chapter summarizes these flow-related studies and presents data and scientific interpretations that have contributed to the recommendations that are presented in Chapter 8.

5.1 Microhabitat Studies

The physical space required for an aquatic organism to develop, grow, or reproduce can be described as micro-habitat. For anadromous salmonids in the Trinity River, the amount of microhabitat available at a given streamflow was determined from area measurements, structural descriptions, and quantification of hydraulic conditions. A study of microhabitat, undertaken as part of the TRFE, included the development of site-specific habitat suitability criteria (curves) and the derivation of the relation between microhabitat and streamflow for riverine life stages of chinook salmon, coho salmon, and steelhead. The terms habitat or physical habitat as they appear in this section of this report should be interpreted as referring to micro-habitat.

5.1.1 Habitat Suitability Criteria

For each life stage of each species studied, habitat suitability criteria (HSC) are used to translate the use of hydraulic and structural elements of rivers into indices of relative suitability for these species. HSC are normalized values of suitability, with the poorest quality conditions receiving a suitability of 0.0 and the highest a suitability of 1.0. In order to quantify the amount of physical habitat available at different streamflows, these habitat suitability indices are used to weight discrete stream areas (cells) according to the quality of habitat conditions (e.g., water depth, water velocity, substrate composition) either directly measured or simulated (i.e., modeled) in each cell.

> Microhabitat can be described as the physical space, and the characteristics of that space, required for an aquatic organism to develop, grow, and reproduce. Understanding the microhabitat needs of anadromous salmonids of the Trinity River was necessary to derive relations between streamflows and the amount of habitat in the river.

One task identified during the initial design of TRFE studies was the development of site-specific habitat suitability criteria in the Trinity River. The original Plan of Study (Appendix I) describes the objective of the task as "to develop habitat preference criteria quantifying depths, velocities, substrates, and cover requirements for chinook and coho salmon and steelhead spawning, incubation, rearing, holding, and migration."

Much of the following information (Sections 5.1.1 and 5.1.2) has been previously reported in Flow Evaluation Annual Reports (USFWS, 1985-91) and by Hampton (1988, 1997). These reports provide much greater detail than is presented here. Additional unreported data collected during the later years of the TRFE, and analyses that have affected initial results, are included in this report. The habitat suitability criteria contained herein are the final result of this task, incorporating both information acquired during the research and contemporary criteria curve developmental techniques that evolved during the course of the TRFE.

> Habitat suitability criteria are used to translate hydraulic and structural elements of rivers into indices of relative suitability for the organism being studied. Habitat suitability criteria are normalized values of suitability, with the poorest quality conditions receiving a suitability of 0.0 and the highest a suitability of 1.0.

5.1.1.1 <u>Study Sites</u>

Fourteen study sites where fish observations would be made and habitat-use data collected were selected within three major river segments between Lewiston Dam and the Klamath River confluence at Weitchpec, a distance of approximately 112 miles. The river segments separate the Trinity River hydrologically and by overall character from Lewiston Dam to the North Fork Trinity River, the North Fork to the South Fork Trinity River, and the South Fork to the Klamath River (USFWS, 1985). The study sites were chosen by professional judgment as being representative of each segment. Nine sites were located in the segment directly below the dam (thought to be most affected by TRD operations), two were in the middle segment, and three sites were located in the lower segment (Figure 5.1). Data were collected to describe the habitat conditions selected by overwintering steelhead juveniles at five additional study sites that contained microhabitat conditions available during the winter season (USFWS, 1985). Two of these study sites were located in side channels and three were in the main river channel.

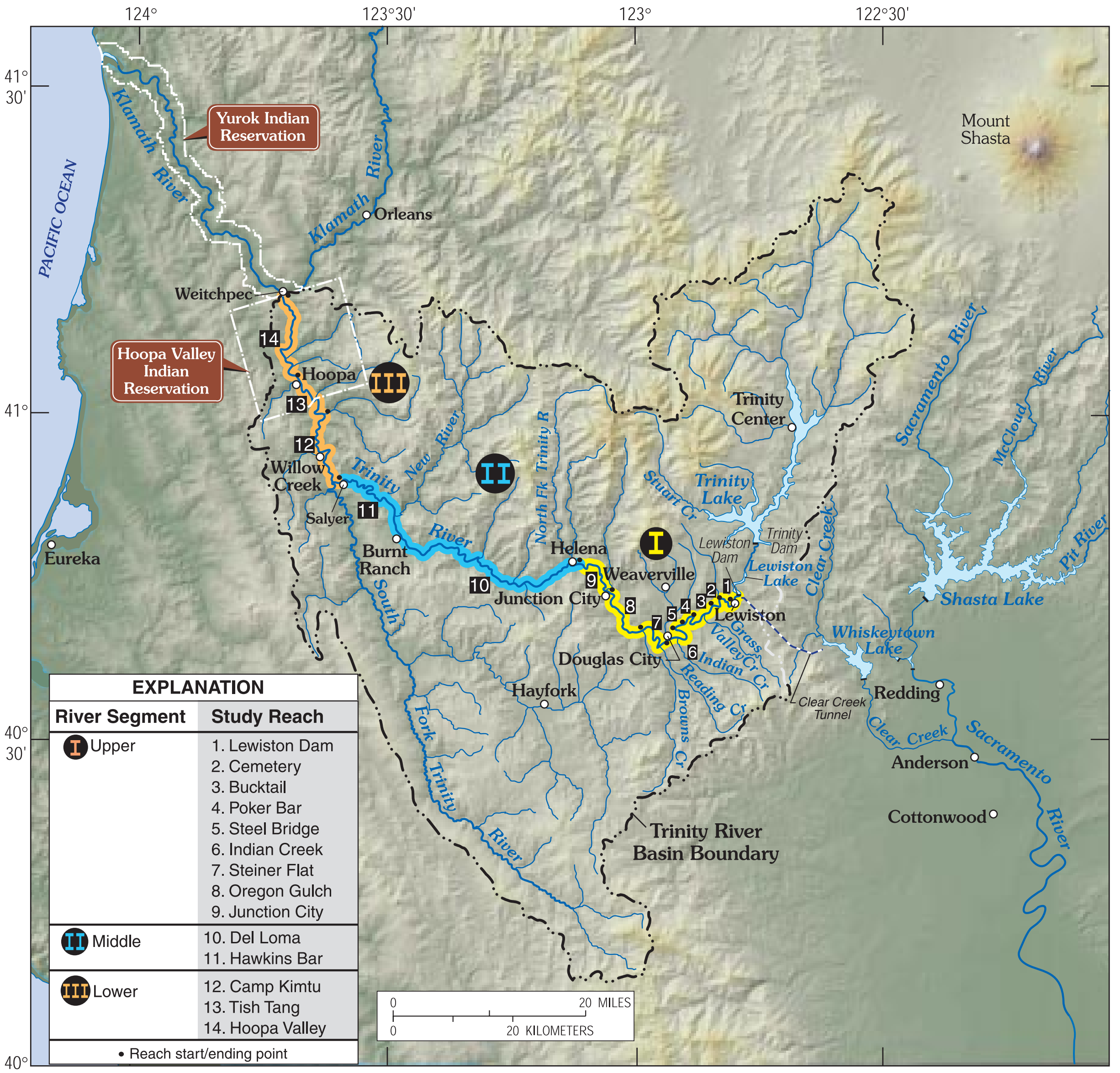


Figure 5.1. The Trinity River Flow Evaluation Study area.

5.1.1.2 Methods for Habitat Suitability Criteria

Habitat-use data were collected for all life stages of chinook salmon, coho salmon, and steelhead as fish were encountered within the study sites. Sampling methods included both direct and indirect observational techniques. Direct observations were made underwater by snorkelers and above water from the river banks or a raft. During extended periods of poor water clarity, indirect observations were made using a backpack electrofisher or a bag seine. Observations were made when Lewiston Dam releases were between 300 and 450 cfs, a moderate level of flow at which diverse depth and velocity habitat conditions were present in the river.

When a fish or group of fish was located, 14 parameters were measured (or described) and recorded (USFWS, 1986; Hampton, 1988). These included species, size (fork length), water depth (total), water velocity (mean water column), substrate (dominant particle size, subdominant particle size, and percent embedded), and cover type (dominant, subdominant, and quality). Rearing salmonids less than 2 inches (fork length) were considered fry, those larger than 2 inches were considered juveniles, and fish with a fork length greater than 7.9 inches were considered adults. Schools of fish were treated as single observations at the focal point of the school.

Observations of habitat availability were made in order to generate habitat preference criteria (curves), as was specified in the original Plan of Study (Appendix I). Preference criteria are derived from the ratio of habitat use over habitat availability (data, by physical variable). Availability data were collected initially by taking a minimum of 150 random microhabitat measurements at each study site for each discharge sampled. Sampling locations were determined from previously prepared tables of paired random values of a length–width grid of the sites. Availability data were collected for essentially the same parameters as for habitat use. This process was man-power intensive and time consuming, leading to an alternative that allowed field efforts to be allocated more toward collection of habitat-use data. Using this alternative, physical habitat availability data were obtained from hydraulic simulation models that were run on transects located within the fish-observation study sites. The method is described in detail in the 1986 Annual Report (USFWS, 1986) and includes a comparison of the two approaches showing the similarity in estimates of habitat availability between them. Results of the comparison are also reported by Aceituno and Hampton (1987) and Hampton (1988).

Chinook and coho salmon fry prefer shallow stream margins with very slow water velocities, while steelhead fry preferred edge habitats adjacent to riffles and swift runs.

Initial data frequencies (bar histograms) of habitat use by each species and life stage were constructed following the guidelines presented by Bovee and Cochnauer (1977). Frequency intervals for depth and velocity were calculated using the Sturges Rule, as cited by Cheslak and Garcia (1987). Resulting frequency bar histograms were subjected to two series of three-point running mean filters and normalized to a maximum value of 1. For cover, a simple frequency bar histogram was constructed using only the dominant cover type. Two frequency bar histograms were constructed for substrate, one a histogram of dominant substrate types and the other a histogram of percent embedded in fines. These were also normalized to a maximum value of 1, with each remaining interval given a value proportional to its relative occurrence.

Preference criteria development followed the early theories and procedures described in the documentation of the Instream Flow Incremental Methodology (Bovee, 1982). These criteria were computed by ratios of use intervals to corresponding availability intervals (forage ratios). Curve-smoothing techniques were applied to those criteria that still exhibited large deviations between adjacent intervals. Resulting preference criteria were then normalized to values between 0.0 and 1.0.

5.1.1.3 <u>Results for Habitat Suitability Criteria</u>

<u>Criteria Data Collection</u>

The first 2 years of data collection in all three segments produced 2,418 fish observations and associated microhabitat measurements for four salmonid species in four life stages (USFWS, 1986). This number was later pared to 1,809 observations for three salmonid species in three life stages (Hampton, 1988). This reduction occurred because data for brown trout and holding adult salmon were not included. Subsequently, this data set was further restricted to (1) observations made above the North Fork Trinity River where habitat availability data for preference criteria could be generated from hydraulic simulation modeling; and (2) data

Juvenile life stages of chinook salmon, coho salmon, and steelhead have divergent microhabitat preferences; with chinook preferring deeper areas with higher water velocities; coho preferred low-velocity conditions such as were present in backwaters, side channels, and pools; and steelhead preferred run, riffle, and riffle-pool transition habitats that provided diverse velocity conditions.

collected by direct observation only. Data collected in later years for steelhead fry, overwintering steelhead juveniles, and holding adult steelhead were added to the data set, resulting in a final total of 1,721 observations (Table 5.1).

Chinook salmon fry were most often found along the edge of the stream where very slow water velocities (Figure 5.2) and structural cover were present. Woody debris, undercut banks, and cobble substrates provided velocity shelters for chinook fry and possibly functioned as escape cover from surface-feeding predators. As chinook salmon grew larger, they became less dependent on edge habitats and began to use areas with higher water velocities in deeper water (Figure 5.3). Object cover continued to provide shelter from swift water velocities in run and riffle habitats. In deep-pool habitats, schools of juvenile chinook salmon positioned themselves in relation to eddies and shear velocity zones where food items could be easily taken in the drift. In these habitats, most juvenile salmon would feed near the water surface, retreating to deeper water between feeding forays. At night, chinook salmon fry and juveniles congregated in areas with slow water velocities, usually close to the river bed.

The majority of chinook salmon redds were located in water from 0.8 to 2.5 feet deep (Figure 5.4). The range of water velocities measured at established redds was relatively broad, but most redds had mean column velocities between 0.8 and 2.6 feet per second (fps). For redd construction, spawning chinook salmon used gravels and cobbles 2 to 6 inches in diameter that were less than 40 percent embedded in fines (Figure 5.5). Areas closer to the river banks were generally favored for redd excavation over areas in midstream.

Low-velocity areas with clean cobble substrates were preferred overwinter habitat for juvenile steelhead.

Coho salmon fry selected microhabitats similar to those of chinook salmon fry (Figure 5.6) and the two species were often found together. Agonistic behavior between the species was rarely observed. As coho salmon became larger they did not shift their habitat selection to areas of faster velocity as did chinook salmon (Figure 5.7). Juvenile coho were usually found in low-velocity conditions such as were present in backwaters, side channels, and along stream edges adjacent to slow runs and pools. These habitats often contained cover such as woody debris, aquatic vegetation, and overhanging vegetation. Spatial segregation between juvenile coho and chinook salmon was common owing to differences in microhabitat selection.

Coho salmon spawned in slightly shallower, slower water velocity areas in comparison with chinook salmon. Most coho salmon redds were constructed in water from 0.5 to 2.0 feet deep with water velocities between 0.5 and 2.2 fps (Figure 5.8). Gravels and cobbles 1 to 3 inches in diameter and less than 20 percent embedded in fines were favored for redd construction (Figure 5.9).

Steelhead fry preferred edge habitats adjacent to riffles and swift runs where they selected focal points close to the substrate or instream objects providing velocity shelters. Unlike the fry of chinook or coho salmon, steelhead were often observed in the turbulent conditions found in shallow riffles. Overall, the depths utilized by steelhead fry were shallower than

Table 5.1. Summary of the total fish numbers used for criteria curve development collected in the Trinity River above the North Fork Trinity River, 1985-1992.

Species	Life Stage	Number of Observations
Chinook Salmon	Fry	345
	Juvenile	251
	Spawning	311
Coho Salmon	Fry	131
	Juvenile	82
	Spawning	107
Steelhead/Rainbow Trout	Fry	80
	Juvenile	185
	Adult Holding	44
	Spawning	88
	Over-Wintering	97
Total		1,721

those used by salmon fry and the water velocities were significantly higher (Figure 5.10). Steelhead fry were rarely observed in monotypic mesohabitats such as long, slow runs or pools.

Juvenile steelhead preferred run, riffle, and riffle-pool transition habitats that provided diverse velocity conditions. They showed a distinct preference for higher water velocities than did juvenile salmon (Figure 5.11) and were efficient in their use of velocity shelters. In riffles and across the tail end of run habitats, steelhead used boulders and large cobbles to establish feeding stations that they actively defended. When found in riffle-pool transition habitats, juvenile steelhead were usually positioned below the ledge located at the upper boundary of the pool. Here the fish were sheltered from the swifter surface current, which conveyed invertebrate drift from the riffle upstream. Microhabitats selected by steelhead juveniles during the winter season had slower water velocities than those used in other seasons (Figure 5.12) and were characterized by clean cobble substrates.

Overwintering steelhead juveniles were reclusive and most often found underneath cobbles or boulders (Figure 5.13).

Observations were made for both spawning and holding adult steelhead. The range of depths at which redds were constructed was relatively narrow and generally shallower than for the salmon species— although preferred velocities were much the same as for coho salmon (Figure 5.14). Spawning steelhead preferred gravel from 1 to 3 inches in diameter that was less than 20 percent embedded in fines (Figure 5.15). It is obvious from the depth distribution for the 44 holding steelhead adults observed that this life stage is very flexible in its depth requirements. Adult steelhead were found holding in water from 1.5 to 10 feet deep with preferred holding water velocities ranging from 1.0 to 2.5 fps (Figure 5.16).

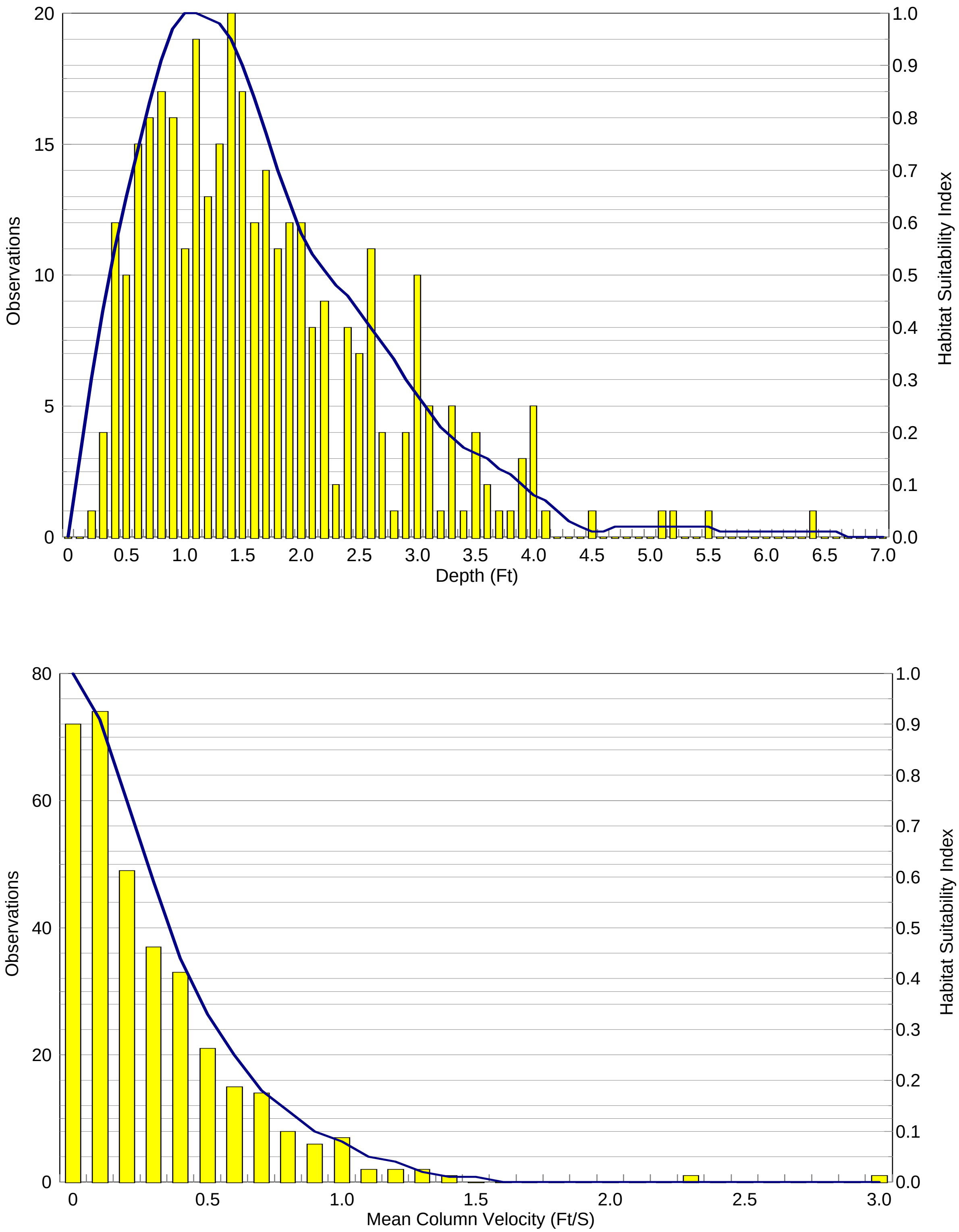
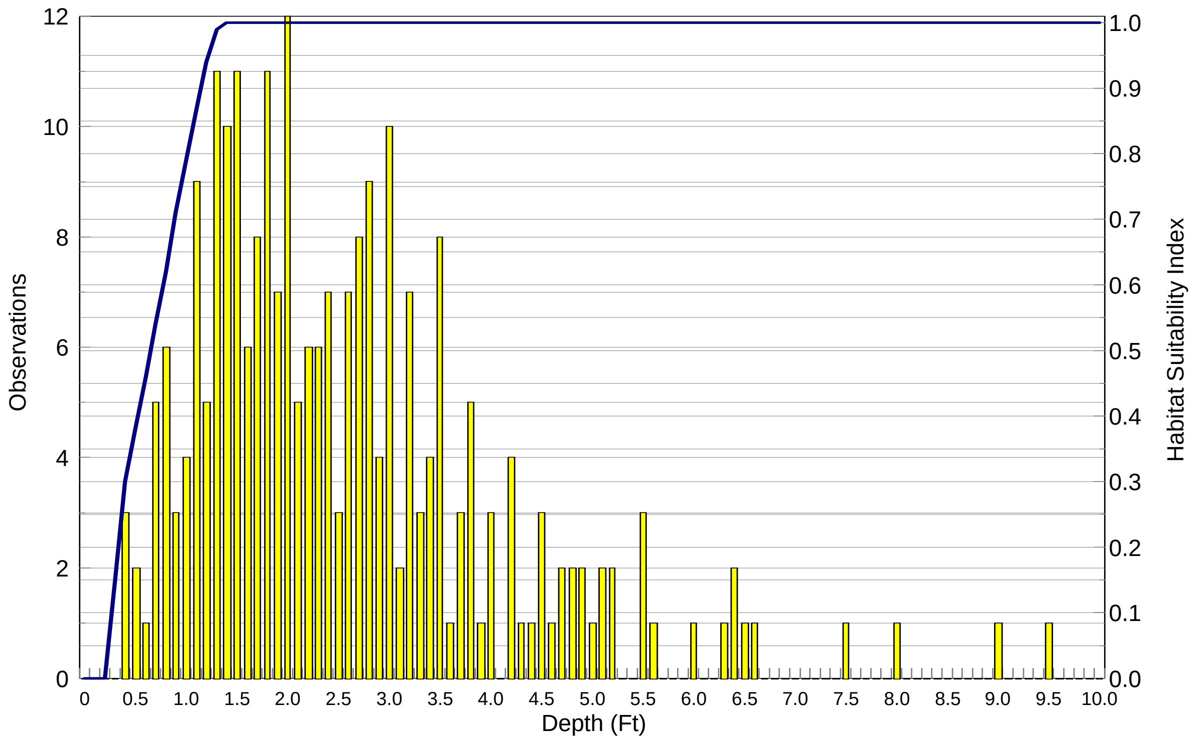


Figure 5.2. Chinook salmon fry observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=345).



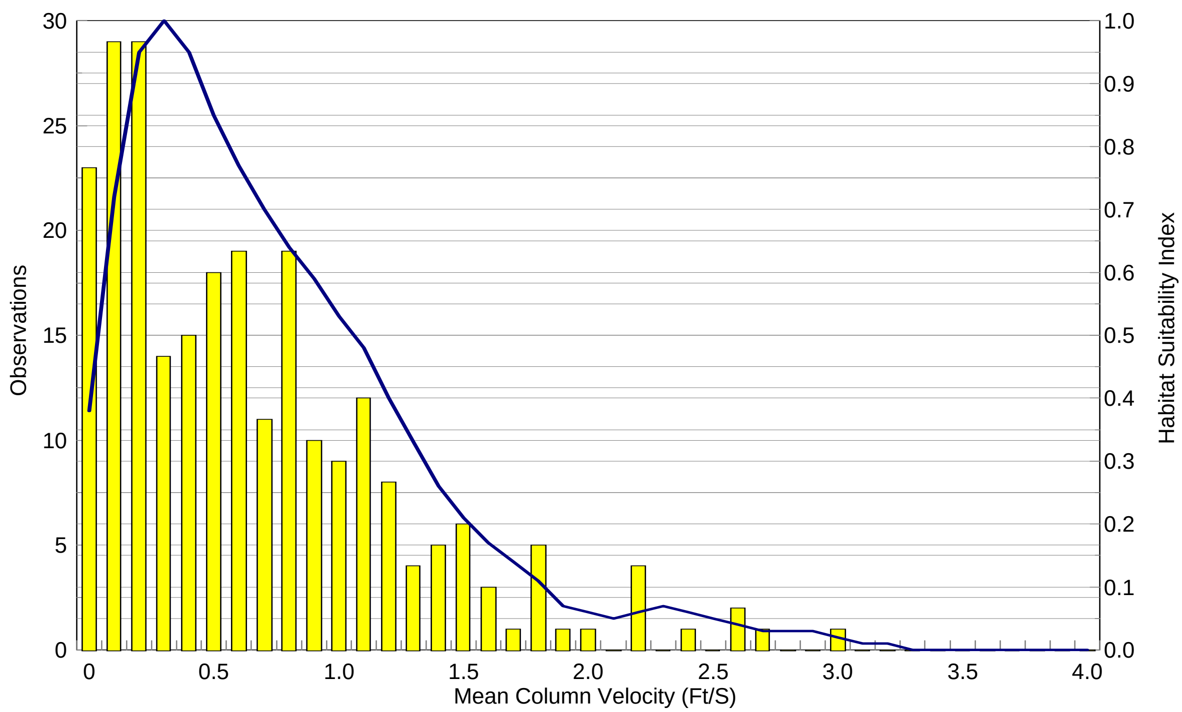


Figure 5.3. Chinook salmon juvenile observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=251).

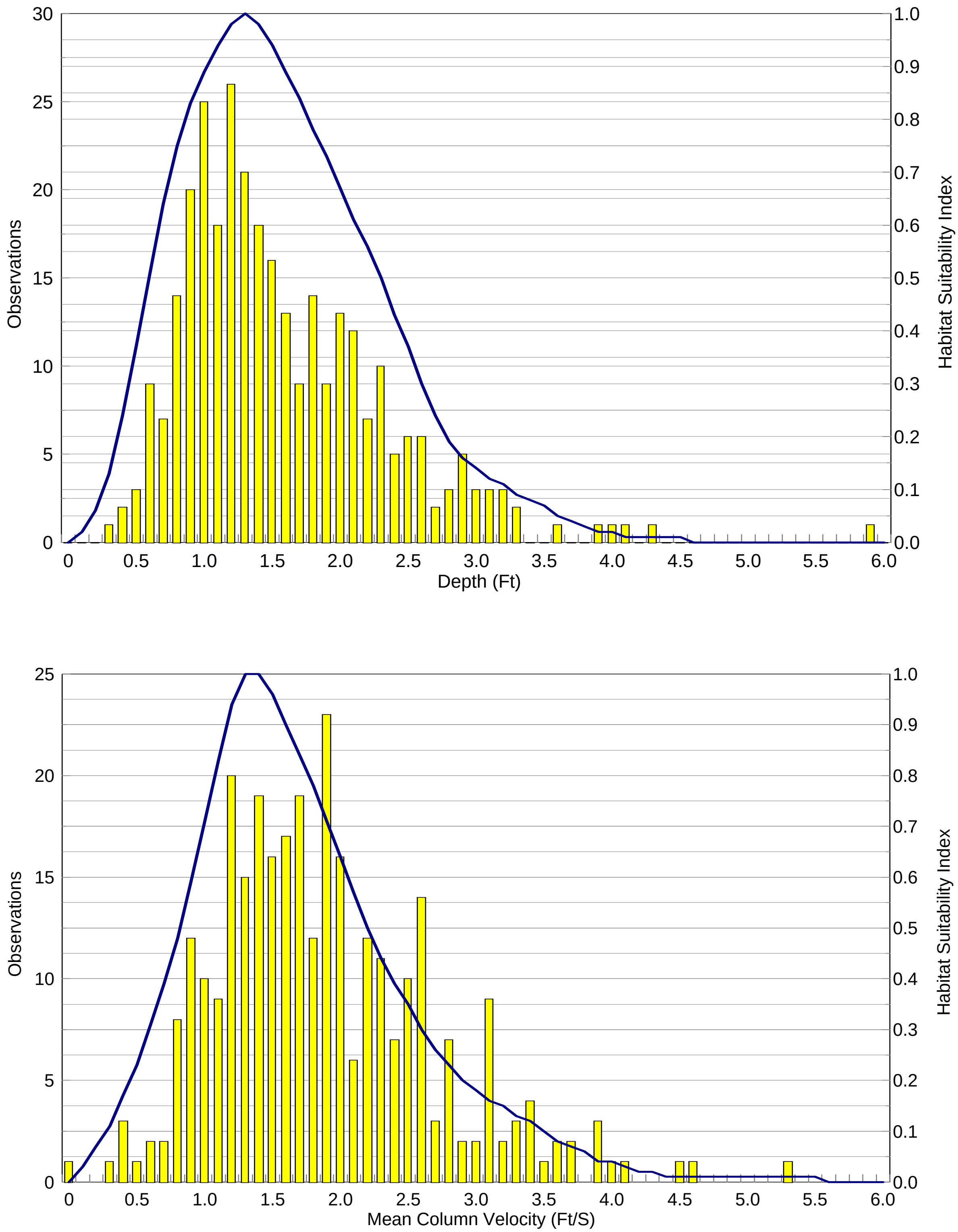
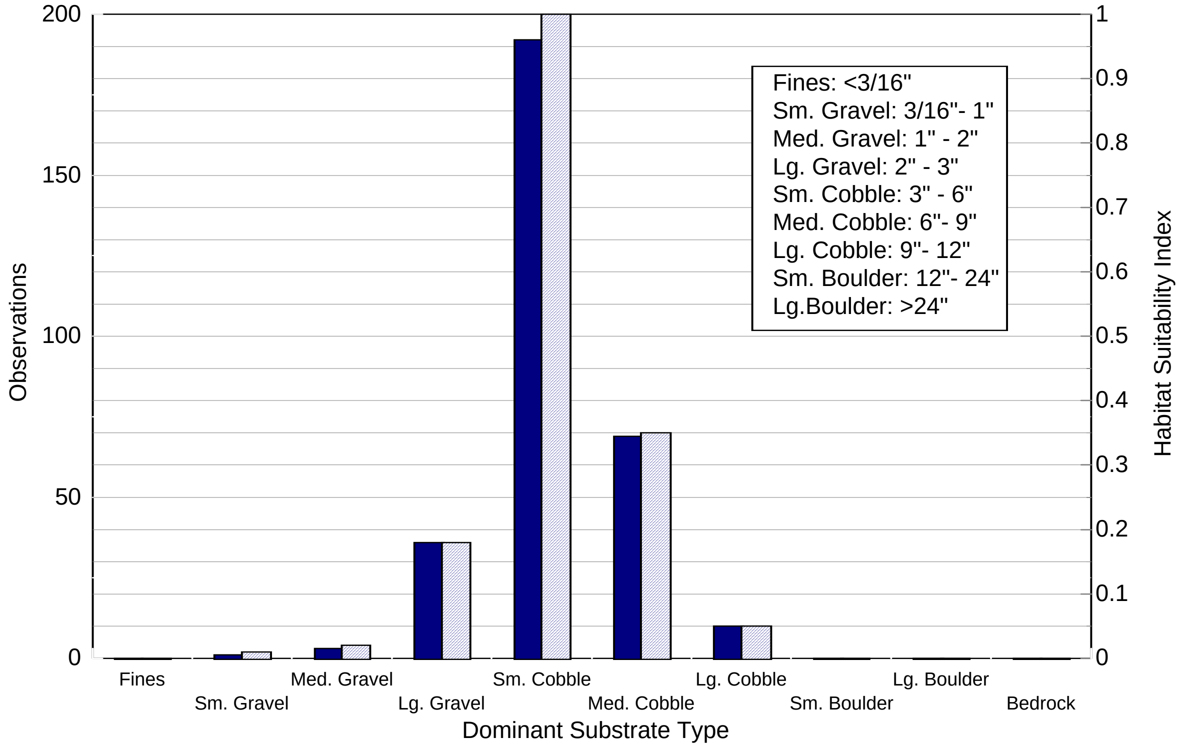


Figure 5.4. Chinook salmon spawning observations (yellow bars) and final water depth and velocity habitat suitability curves (lines), Trinity River, CA. (n=311).



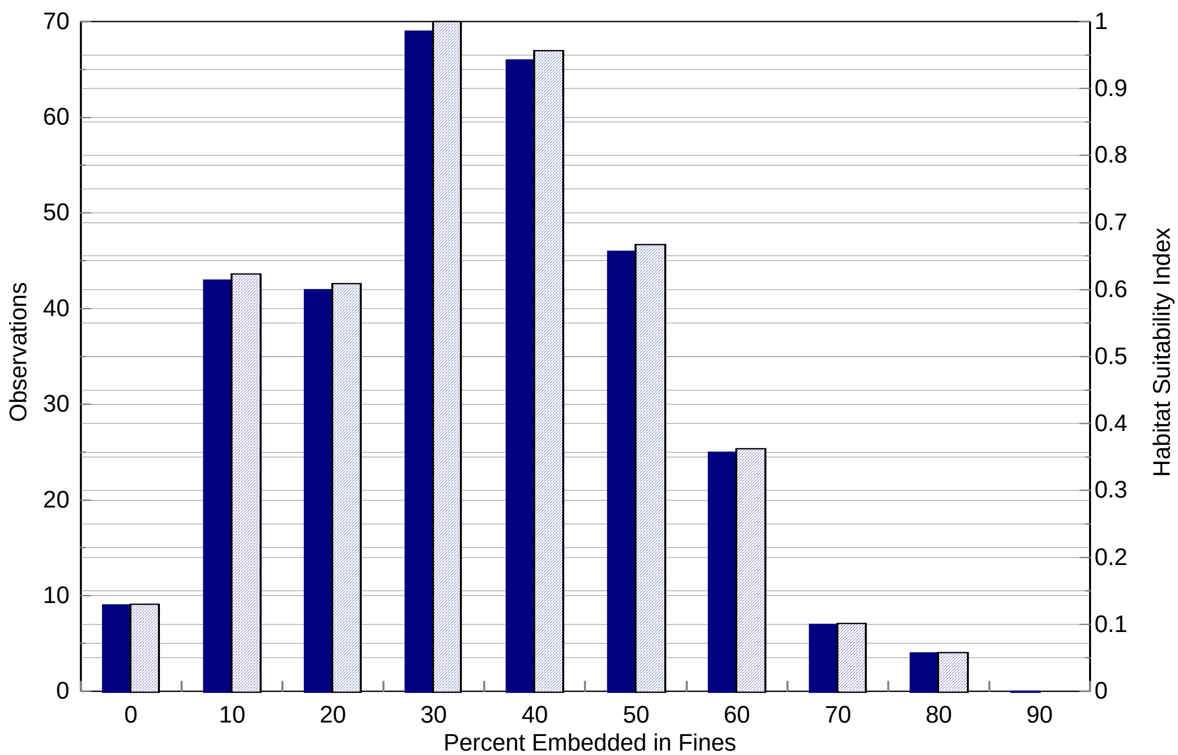


Figure 5.5. Chinook salmon dominant spawning substrate and percent embeddedness observations (blue bars) and final habitat suitability indexes (gray bars), Trinity River, CA.

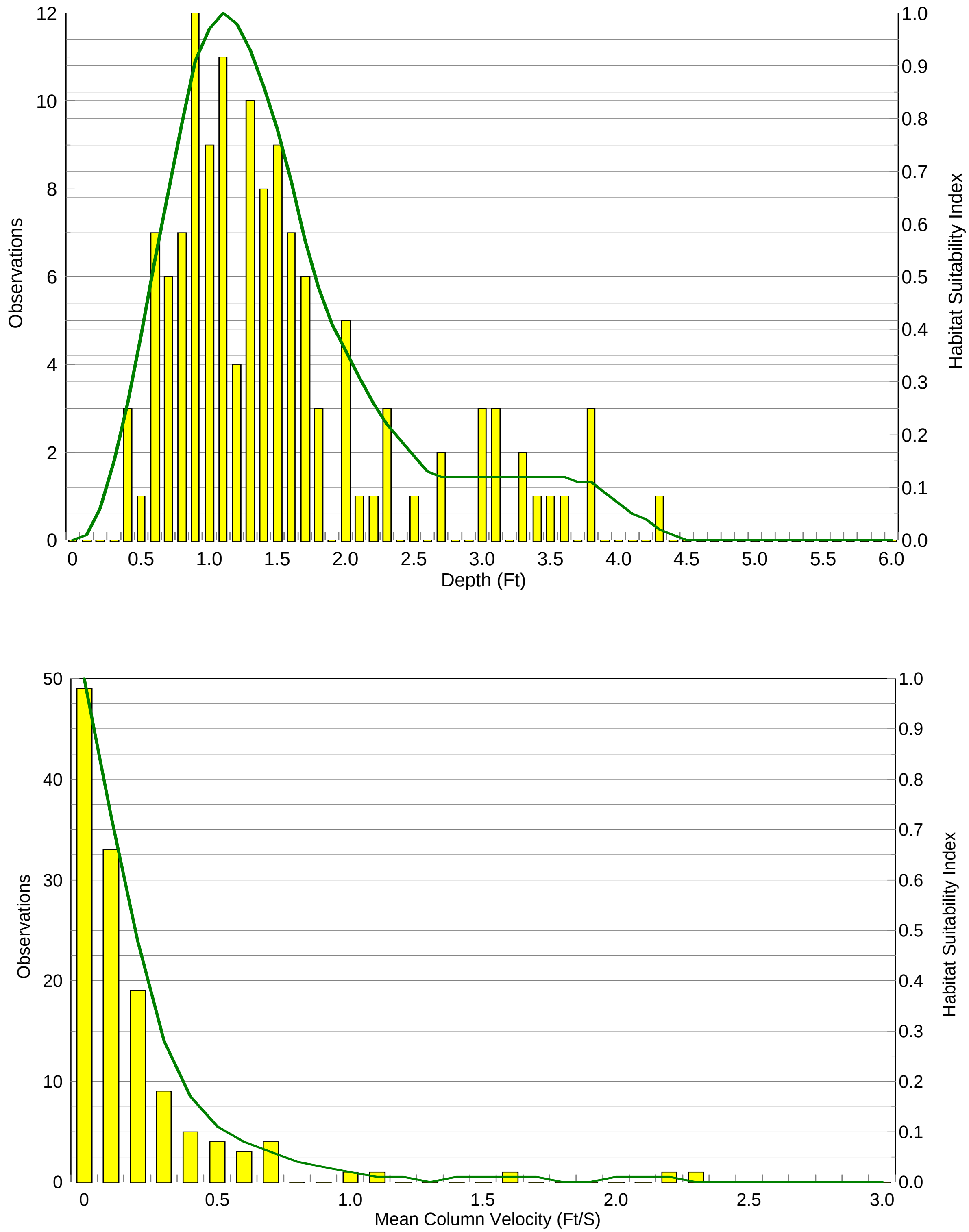


Figure 5.6. Coho salmon fry observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=131).

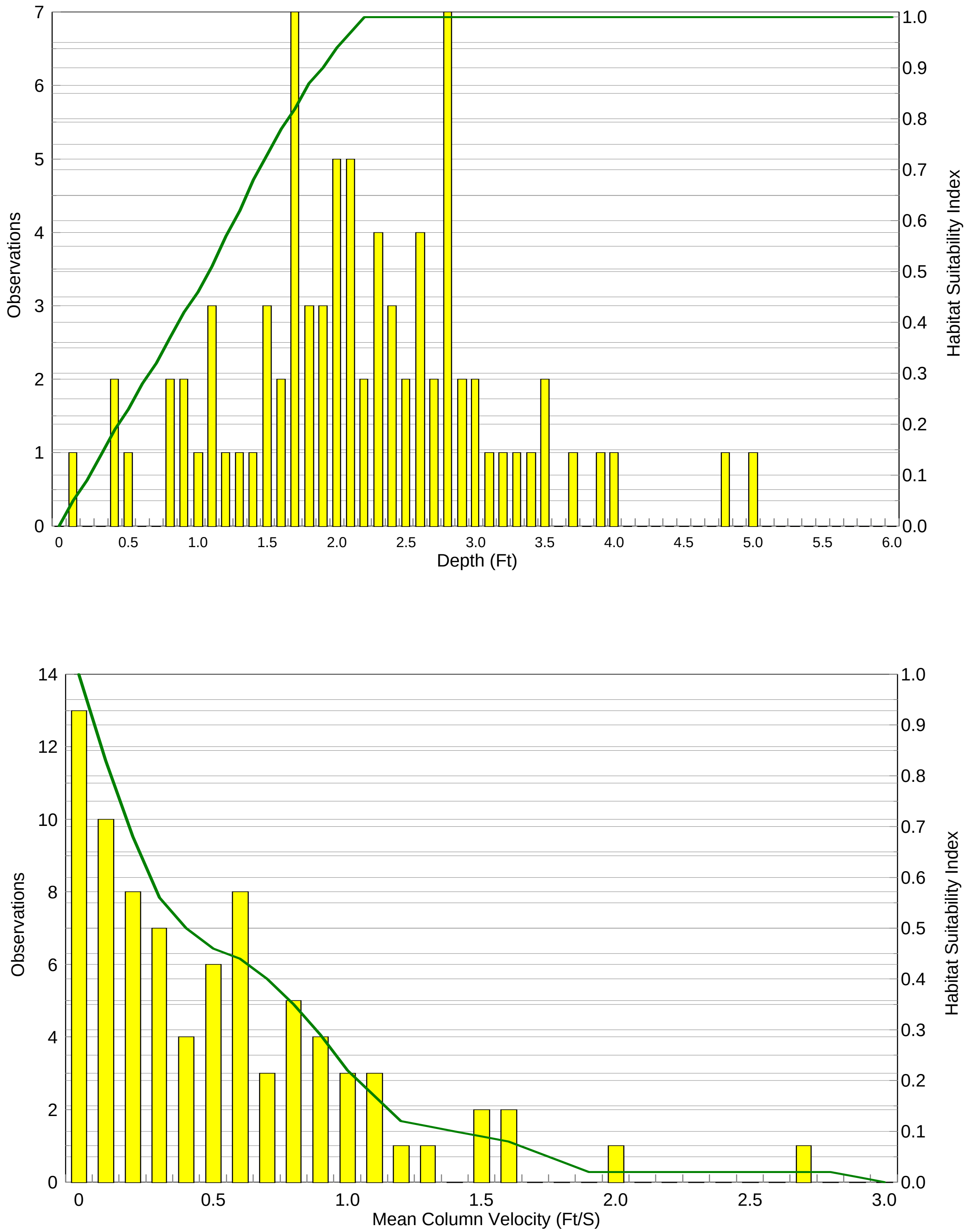


Figure 5.7. Coho salmon juvenile observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=82).

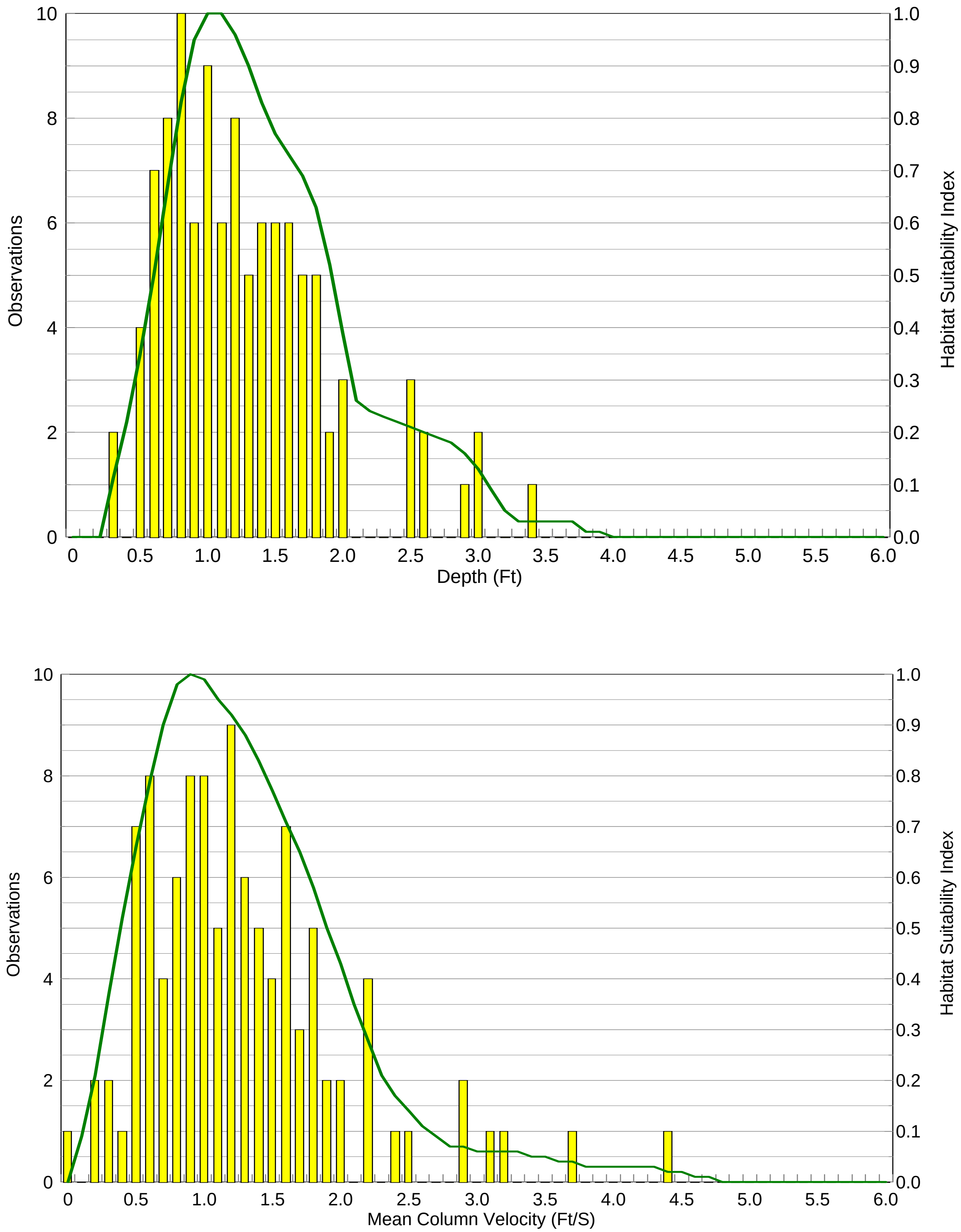
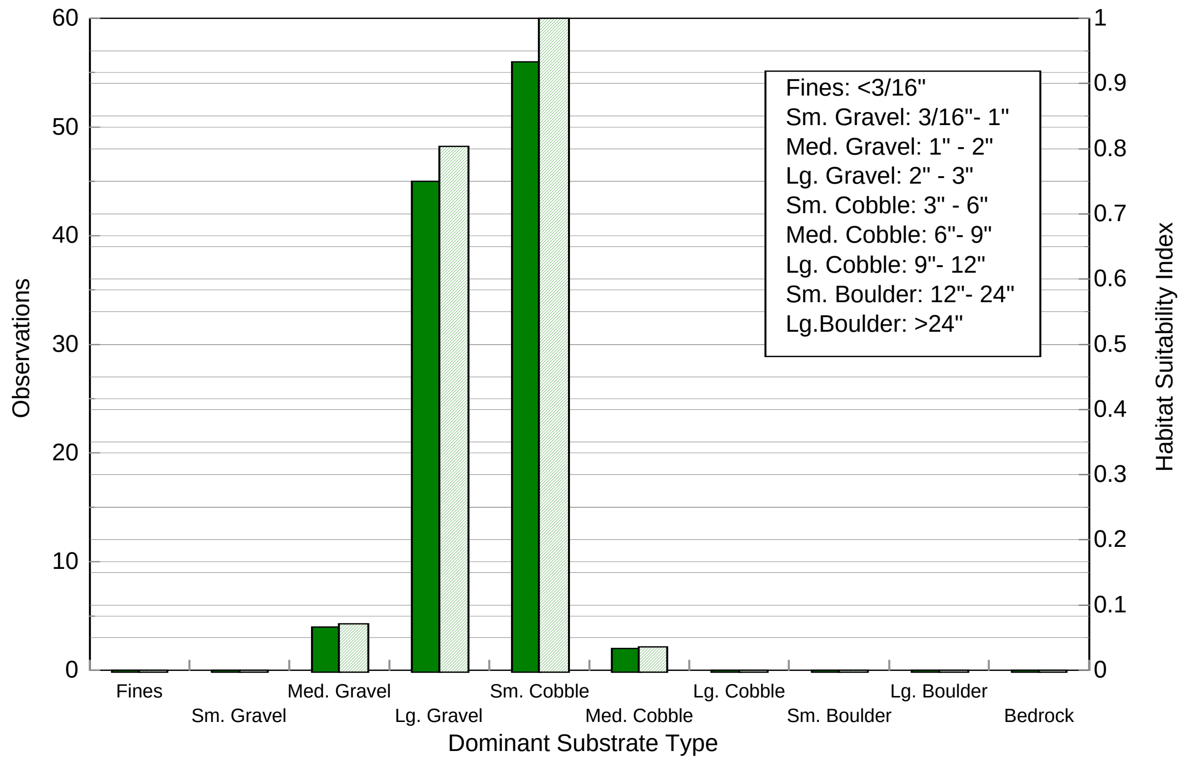


Figure 5.8. Coho salmon spawning observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=107).



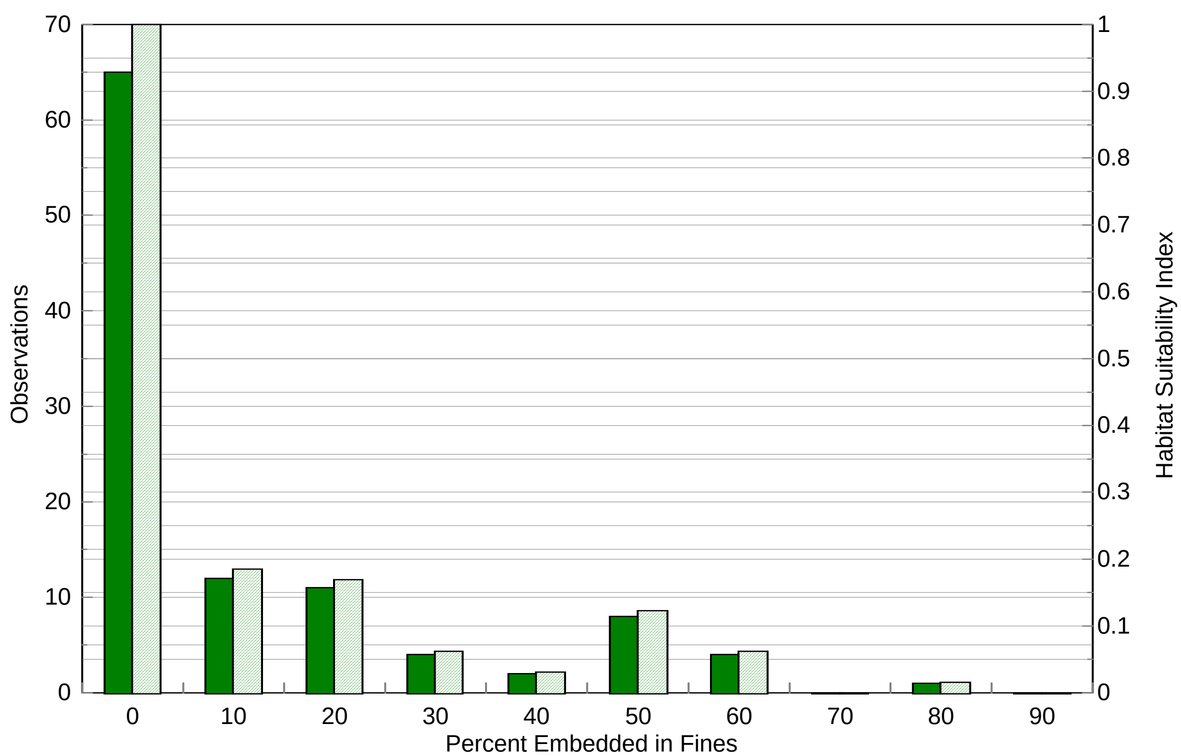
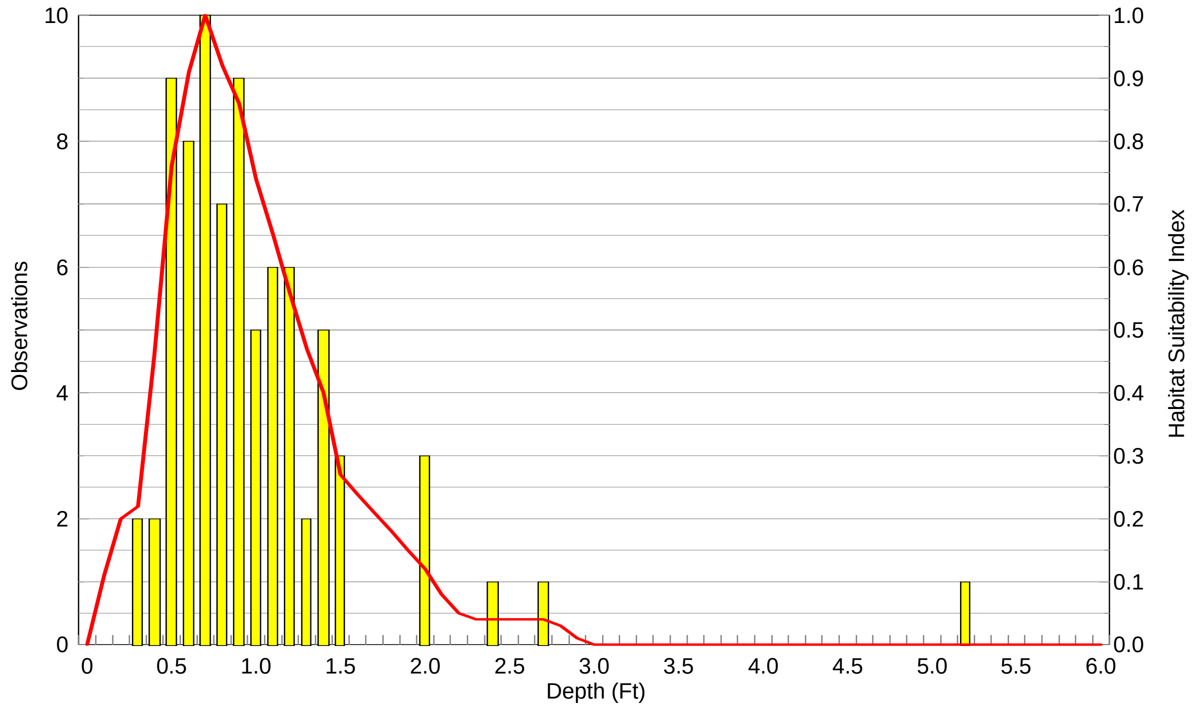


Figure 5.9. Coho salmon dominant spawning substrate and percent embeddedness observations (green bars) and final habitat suitability indexes (gray bars), Trinity River, CA. (n=107).



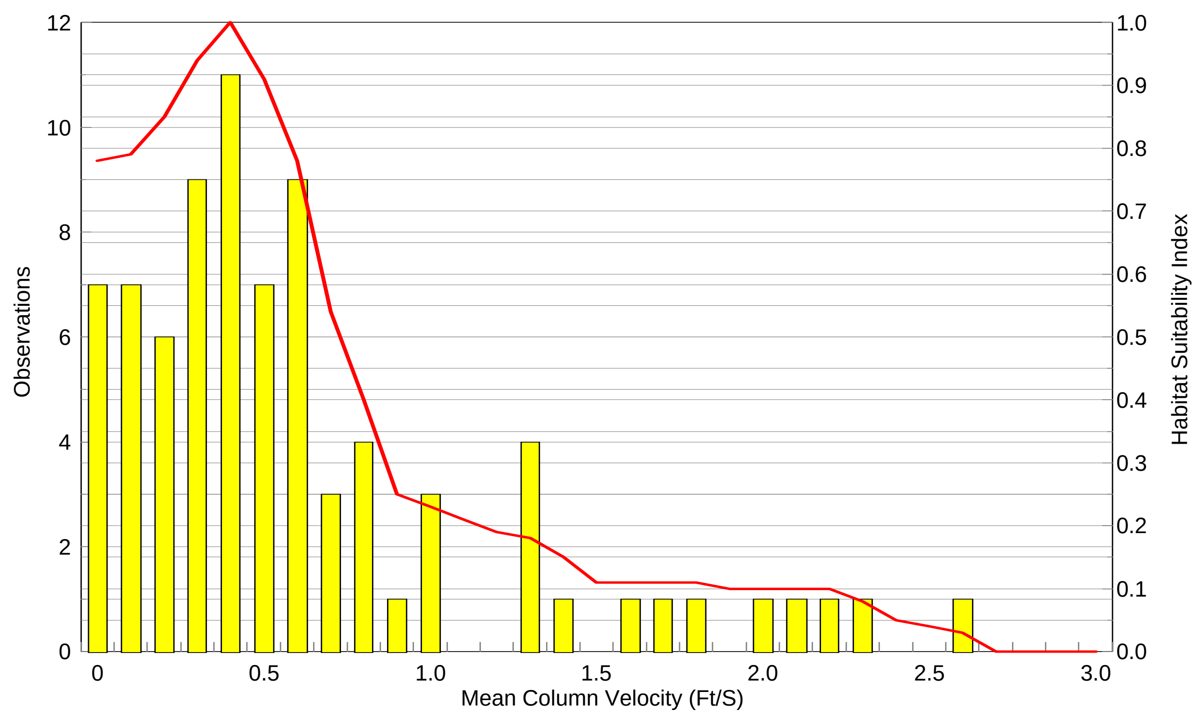


Figure 5.10. Steelhead fry observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=80).

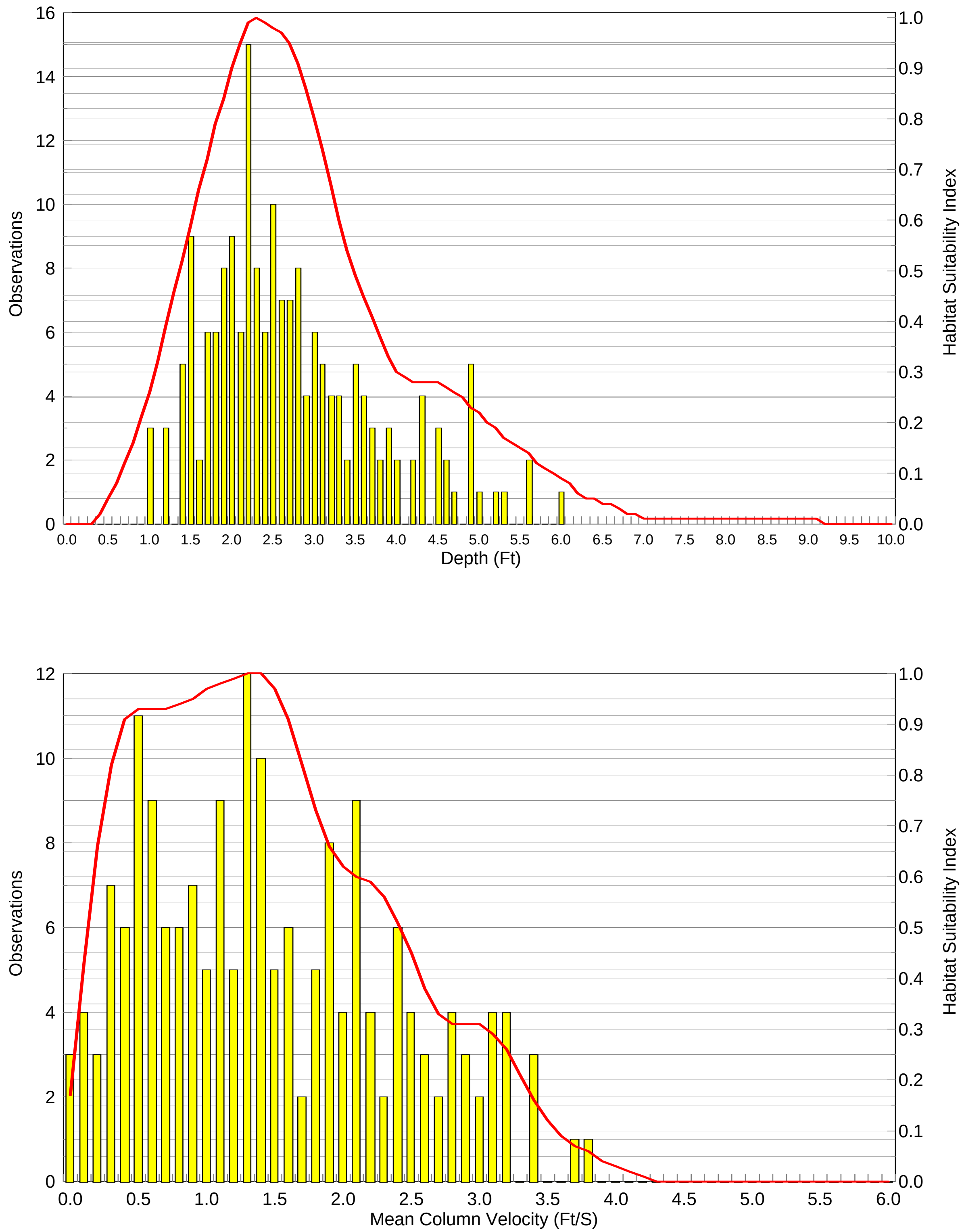
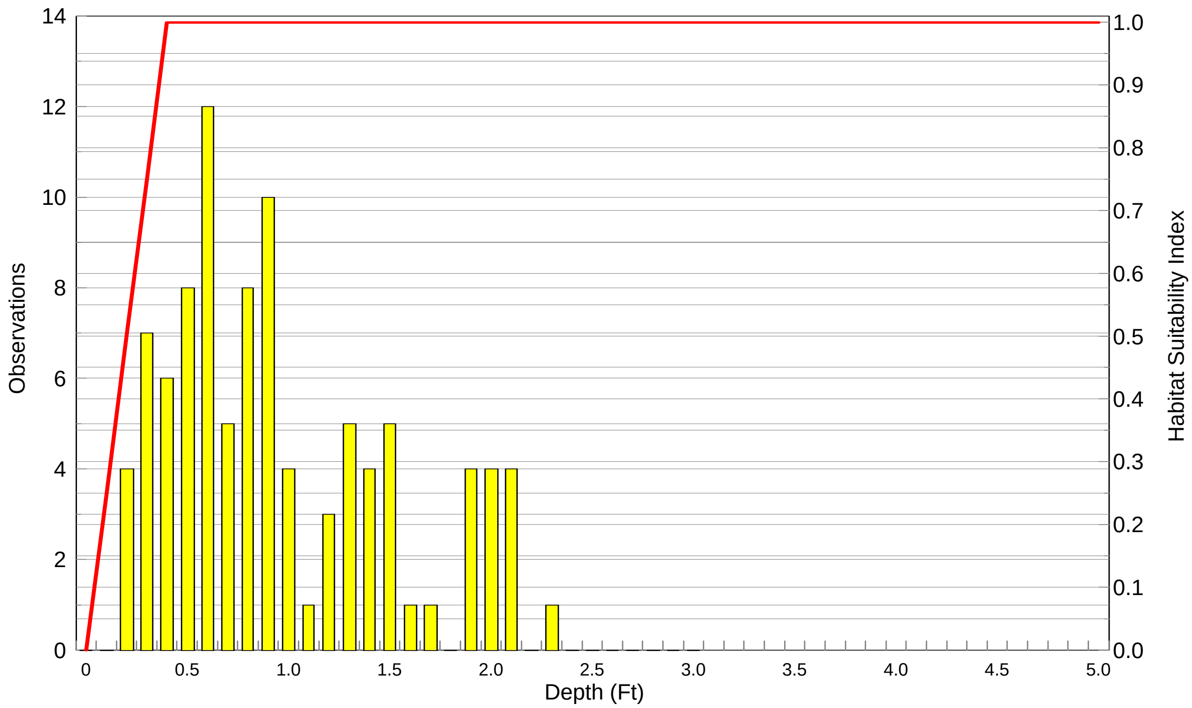


Figure 5.11. Steelhead juvenile observations (yellow bars) and final water depth and velocity habitat suitability curves (line), Trinity River, CA. (n=185).



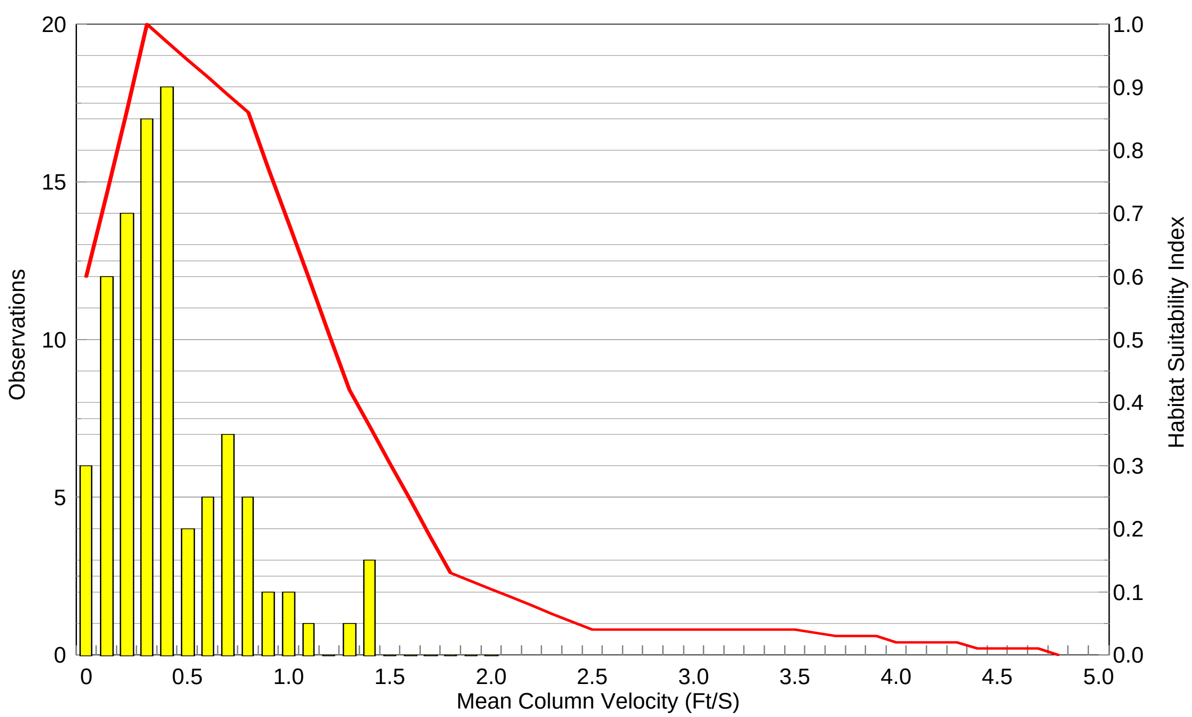


Figure 5.12. Juvenile steelhead overwintering observations (yellow bars) and final water depth and velocity habitat suitability curves (lines), Trinity River, CA. (n=97).

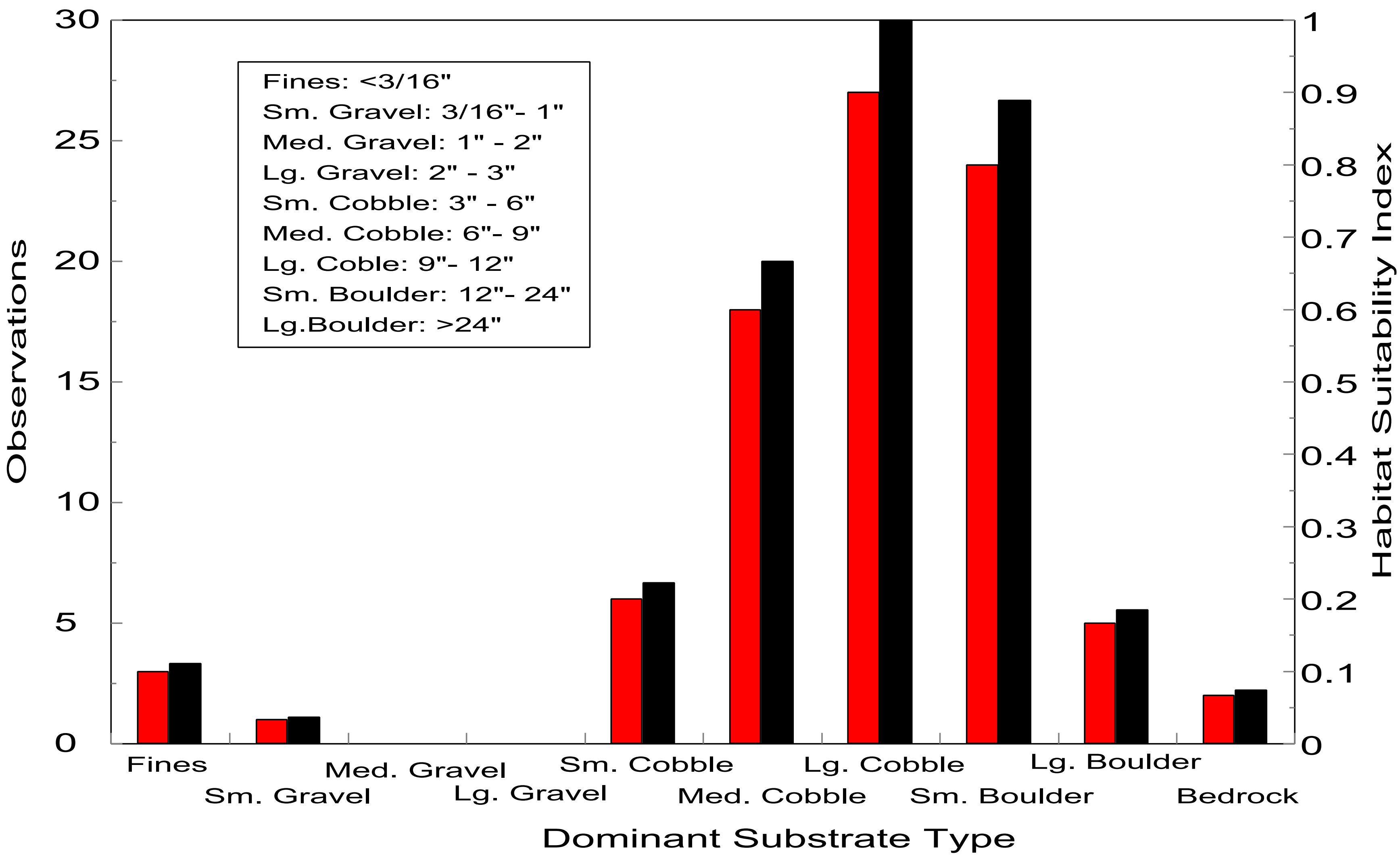
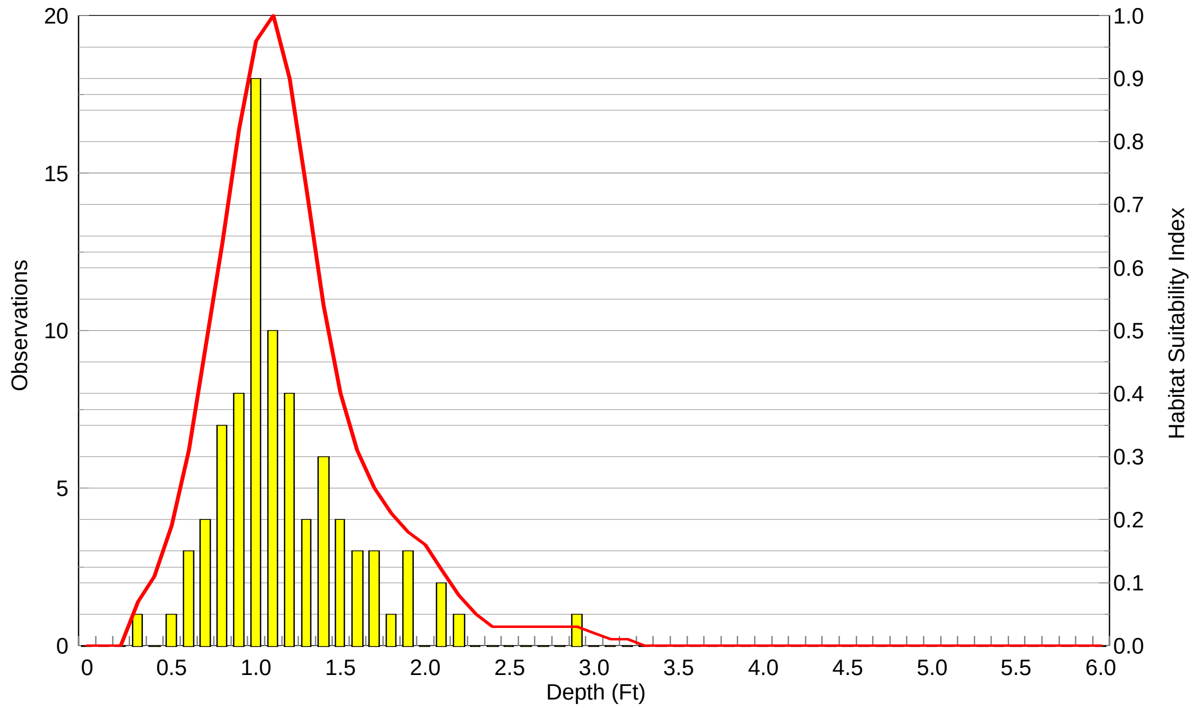


Figure 5.13. Juvenile steelhead overwinter dominant substrate type observation (red bars) and final habitat suitability indexes (black bars), Trinity River, CA. (n=97).



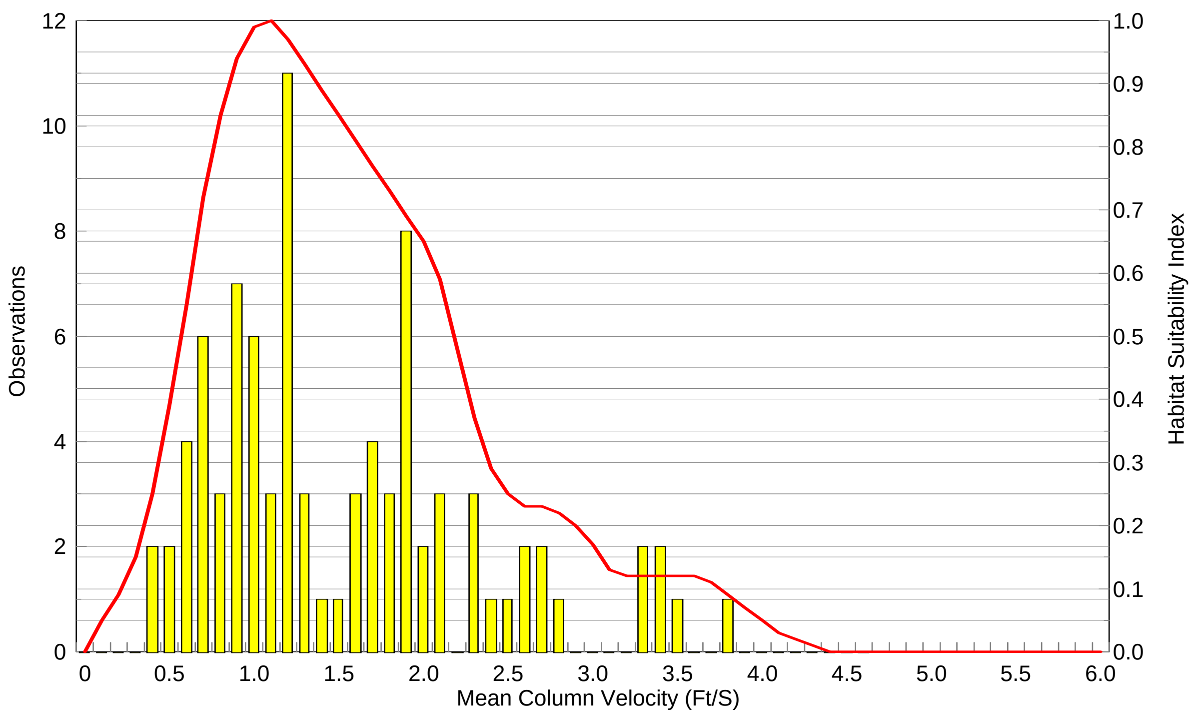


Figure 5.14. Steelhead spawning observations (yellow bars) and final water depth and velocity habitat suitability curves (lines), Trinity River, CA. (n=88).

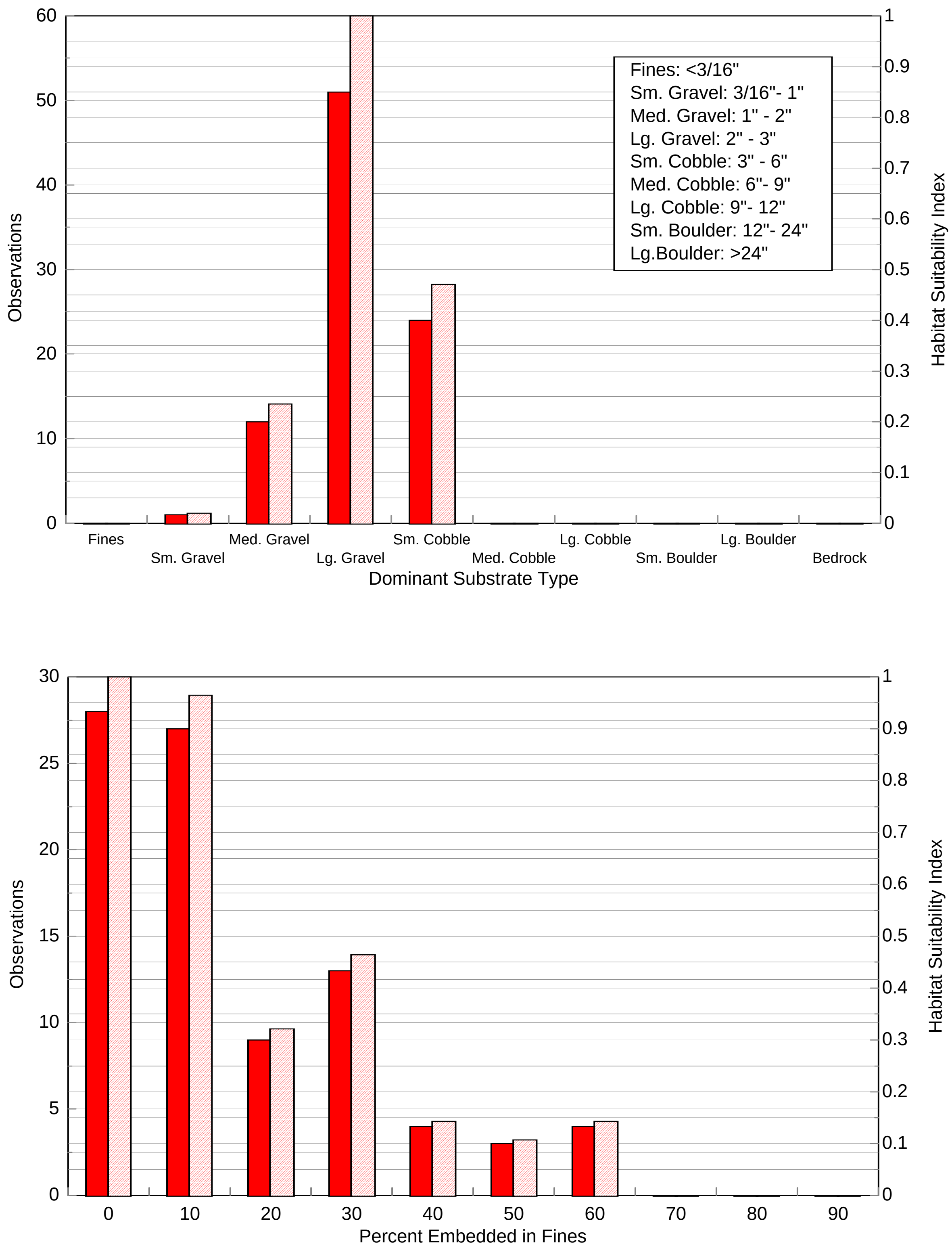


Figure 5.15. Steelhead dominant spawning substrate and percent embeddedness observations (red bars) and final habitat suitability indexes (gray bars), Trinity River, CA. (n=88).

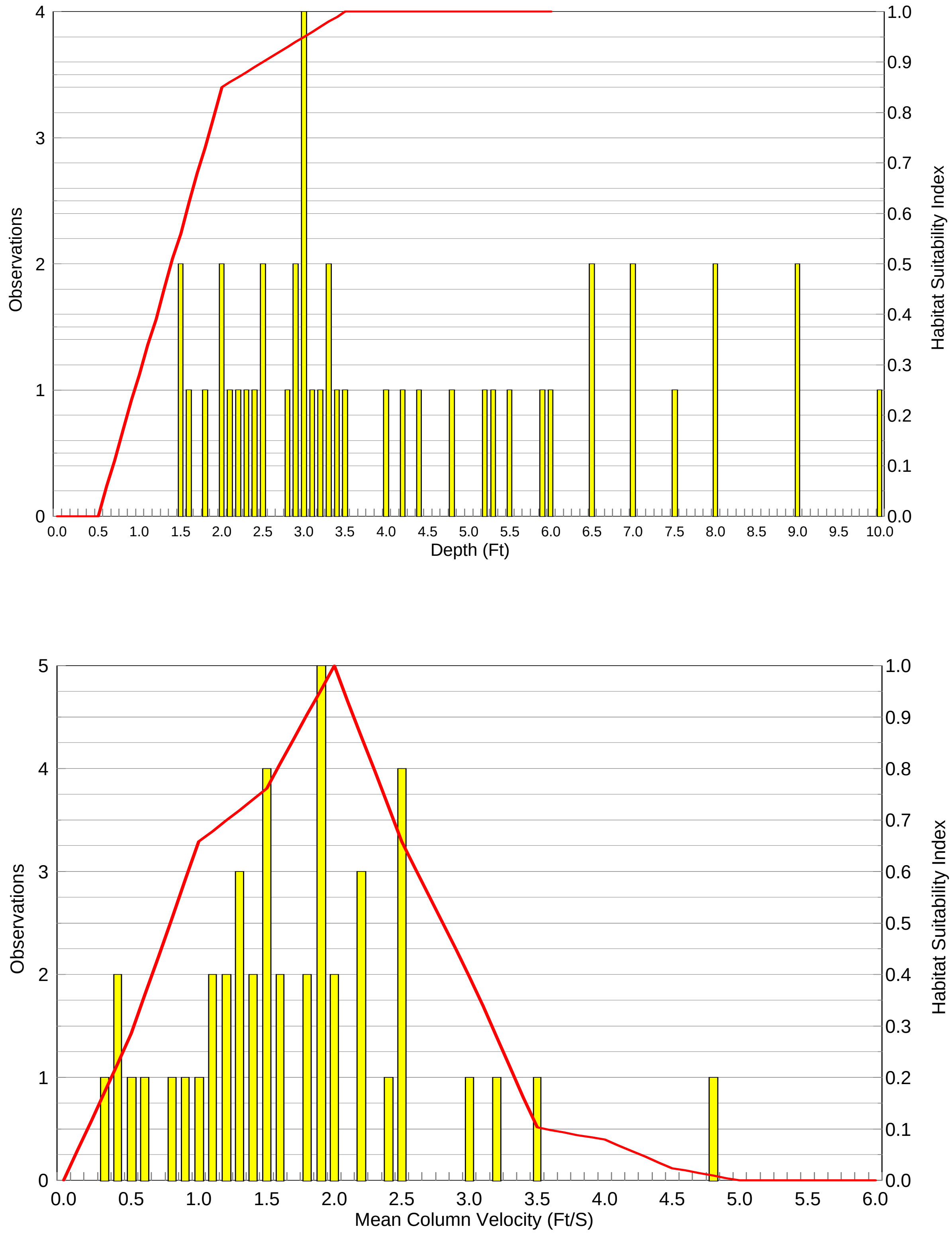


Figure 5.16. Observations of adult steelhead holding (yellow bars) and final water depth and velocity habitat suitability curves (lines), Trinity River, CA. (n=44).

Chinook salmon, coho salmon, and steelhead generally constructed redds in areas with depths ranging from 0.5 to 2.5 feet and velocities ranging from 0.5 to 2.5 feet per second, although each has slightly different preferred depths and velocities. Chinook salmon selected gravel substrates for constructing redds ranging from 2 to 6 inches that were less than 40% embedded in sand, while coho salmon and steelhead selected substrates ranging from 1 to 3 inches and less than 20% embedded in sand.

Criteria Development

The development of the habitat suitability curves went through several iterations during the course of the TRFE. Complications were encountered with the original plan to derive preference curves by the ratio of use to availability. Problems, mostly related to small sample sizes at the tails of the distributions, resulted in preference curves for some species and life stages that were unduly influenced by the habitat selection of only a few individuals within the sampled population. Many of these curves showed highly unusual suitability values that seriously contradicted most of the use observations.

The concern generated over the use of forage ratios to derive preference criteria was reflective of the debate on this issue that was occurring at the time within the instream flow modeling community (Morhardt and Hanson, 1988). A validation study was undertaken to determine if a relation existed between juvenile chinook salmon use of discrete river areas (cells) and cell suitability as defined by the preference criteria. The methods employed and the results of this study are reported in the 1989 Annual Report (USFWS, 1989). Findings indicated that there was poor correlation between juvenile salmon density and habitat suitability. These findings led to the decision to test criteria developed from only utilization data. A second validation study was undertaken in 1991 using the habitat utilization curves developed to determine cell suitability. This study, the methods and results of which are reported in the 1991 Annual Report (USFWS, 1991), found a positive correlation between juvenile chinook salmon density and habitat suitability.

On the basis of these findings, it was decided to use utilization criteria in the physical habitat analyses for the Trinity River. This decision is consistent with that reached by Bovee et al. (1998), who recommended, on the basis of results of curve transferability testing, that preference criteria developed using a forage ratio no longer be used in Physical Habitat Simulation (PHABSIM) applications. Utilization data alone, with the exceptions noted below, were used to develop the final habitat suitability criteria for evaluation of anadromous salmonid physical habitat availability.

The exceptions to stand-alone utilization as final criteria were for depth for juvenile chinook and coho salmon, overwintering juvenile steelhead, and holding adult steelhead. For these curves, depth was retained at a 1.0 suitability at all depths greater than that providing the initial 1.0 value, so that deep water pool habitats would not be eliminated as potential habitat areas. In contrast, the depth suitability for rearing juvenile steelhead was not altered because of the observed heavy use by this species/life stage of shallow riffle and riffle-pool transition areas. Final depth and velocity criteria curves and the substrate criteria used for spawning salmon, steelhead, and overwintering juvenile steelhead are presented in Figures 5.2 to 5.16.

5.1.1.4 Conclusions

> Habitat suitability criteria curves were developed for the Trinity River anadromous salmonids and were used in all analyses of physical habitat availability for the anadromous salmonids that spawn and rear in the Trinity River.

These HSC curves were considered acceptable and were used in all analyses of physical habitat availability for the anadromous salmonids that spawn and rear in the Trinity River. Although HSC curves were derived from data collected in the mainstem above the North Fork Trinity River confluence, these curves were considered acceptable for use in estimating habitat availability in all sections of the Trinity River. Some effects of the bias of habitat availability on the utilization data probably remain in the final criteria curves owing to the original study design, but retention of the use data in its unadjusted form (with the exceptions noted above) was believed to be better than accepting the unsatisfactory results obtained using the forage ratio method. The results of the 1989 and 1991 criteria validation studies support this conclusion.

5.1.2 Habitat Availability

> Physical Habitat Simulation (PHABSIM) was used to estimate the amount of physical habitat available at varying flows for each anadromous salmonid species and life stage.

Identified in the initial TRFE study design was the need to conduct a habitat availability study to determine (1) the amount of salmon and steelhead habitat available in the Trinity River downstream from Lewiston Dam under various flow conditions, and (2) the various levels of habitat rehabilitation that may be achieved either through the Trinity River Basin Fish and Wildlife Management Program or through other resource management actions (Appendix I).

Basic theoretical concepts for the study followed those developed for the PHABSIM component of the Instream Flow Incremental Methodology (Bovee, 1982). PHABSIM is based on a linkage between hydraulic and habitat data obtained from stations (cells) measured across representative stream cross sections (transects), and HSC for hydraulic (depth and velocity) and habitat (substrate and cover) variables. Numerous computer models have been developed as part of PHABSIM, which is described by Milhous et al. (1984). Hydraulic simulations to predict unmeasured flow conditions from measured calibration flow data are optionally part of PHABSIM, as is empirical analysis that computes habitat availability only for the measured flows. Both hydraulic simulation and direct computational analysis were used in this assessment, depending on data availability and inherent limitations of the hydraulic models. A customized computer model was written to calculate habitat availability for all direct computation analyses (Hamilton, 1987). Output of either analysis is in the form of a physical habitat availability index called weighted usable area (WUA). WUA at a given streamflow is the sum of all cell areas in a grid of cells representing the stream, with each cell area weighted by a composite suitability (between 0 and 1.0) for depth, velocity, and substrate or cover at that flow. WUA is displayed graphically in this report for ease of interpretation.

Much of the following information has been previously reported in Annual Reports (USFWS, 1985-91) and in three additional reports prepared by the Service (Gard, 1996, 1997; Hampton, 1997). These reports provide much greater detail than is presented here. This section will summarize the methods employed and the analyses conducted to quantify the amount of physical habitat available for anadromous salmonids in the Trinity River downstream from Lewiston Dam under various flow conditions.

5.1.2.1 Study Sites

Fourteen study sites for physical habitat availability analyses were selected within three major river segments between Lewiston Dam and the confluence of the Trinity and Klamath Rivers at Weitchpec, a distance of approximately 112 river miles (Table 5.2, Figure 5.1). The segments separate the Trinity River by significant changes in hydrology and overall character from Lewiston Dam to the North Fork Trinity River (40 miles), the North Fork to the South Fork (40 miles), and the South Fork to the Klamath River confluence (30 miles). The sites were chosen as being representative of each segment. Nine study sites were placed in the upper segment (Segment I) where the majority of spawning activity for all three anadromous salmonid species occurs, and which, consequently, is also a critical reach for rearing fry; two sites were in the middle segment (Segment II); and three sites were placed in the lower segment (Segment III). Subsequently, two of these sites were eliminated. The Indian Creek site in Segment I had unstable channel conditions owing to copious gravel input from Indian Creek (the Steel Bridge site was used to represent habitat in this area), and the Camp Kimtu site was eliminated following a decision that the Tish-Tang site adequately represented the upper portion of Segment III. In the remaining 12 sites, 127 transects were placed (Table 5.2). Detailed study-site maps are presented in the 1987 Annual Report (USFWS, 1987).

5.1.2.2 Methods for Habitat Availability

The "representative reach" approach, the most common approach for conducting riverine habitat analyses using PHABSIM in the early 1980's, was initially chosen as the method by which physical habitat availability would be quantified on the Trinity River. Using this approach, study sites are considered to be representative of larger sections (reaches) of the river, and transects placed in those sites represent the variable physical conditions within the site and, thus, the reach. The habitat/streamflow functions (WUA) derived at each representative study site are considered valid for the entire reach. After extensive scoping and on-the-river reconnaissance of the Trinity River, study reaches were identified, study sites were selected, and transects were placed at these sites.

> Output from PHABSIM modeling is a physical habitat availability index called weighted usable area.

In the mid-1980's an alternative method for representing instream habitat known as habitat mapping was developed (Morhardt et al., 1983). Using this method, the major habitat types (e.g., riffle, run, deep pool) within a study reach are identified and the linear distance represented by each is determined. Transects are placed in each of these habitat types (usually with replicates) so as to fully represent the range of physical conditions present. Separate WUA functions are derived for each identified habitat type, and a total WUA function is calculated for the reach when the representative distances are considered. A comparison was run using both the representative reach and the habitat-mapping approach on the approximate 26-mile reach from Lewiston Dam to Dutch Creek. The results of this comparison showed little difference between the two methods in calculating total WUA (USFWS, 1989). The results using habitat mapping were used for this segment of the upper reach (hereafter referred to as "Segment IA"), and representative reach results were retained for the remainder of the river. The remainder of Segment I (hereafter referred to as "Segment IB") constituted the reach from Dutch Creek to the North Fork Trinity River.

Field-data collection methods generally followed those prescribed by Trihey and Wegner (1981) and are described in detail in the 1986 Annual Report (USFWS, 1986). In the first year of the study (1985), the intent was to evaluate releases from Lewiston Dam of 300, 450, and 600 cfs. Measurements were made at 300 and 450 cfs to obtain hydraulic (depth and velocity) data at all transects and study sites. However, because of dry-year conditions (defined

Table 5.2. Representative study reaches, Trinity River Flow Evaluation Study, 1985.

	River Segment	Study Reach	Description	No. Transects
IA	Upper	Lewiston Dam	Lewiston Dam to Old Fish Weir	19
		Cemetery	Old Fish Weir to Rush Creek	13
		Bucktail	Rush Creek to Grass Valley Creek	11
		Poker Bar	Grass Valley Creek to Limekiln Gulch	10
		Steel Bridge	Limekiln Gulch to Indian Creek	12
		Indian Creek	Indian Creek to Douglas City	0
		Steiner Flat	Douglas City to Dutch Creek	10
IB	Upper	Oregon Gulch	Dutch Creek to Canyon Creek	9
		Junction City	Canyon Creek to North Fork Trinity	9
II	Middle	Del Loma	North Fork Trinity to Cedar Flat	11
		Hawkins Bar	Cedar Flat to South Fork Trinity	8
III	Lower	Camp Kimtu	South Fork Trinity to Horse Linto Creek	0
		Tish-Tang	Horse Linto Creek to Hoopa Valley	9
		Hoopa Valley	Hoopa Valley to Weitchpec	6

by water-supply criteria), water was unavailable for the 600-cfs release. A wetter year followed and measurements were taken at 800 cfs in 1986.

During the 1986 field season it was obvious that some significant morphological changes had occurred within the river channel at sites below Segment IA in Segments IB, II, and III. These changes were the result of some major flood events in February and March of that year. The most significant changes occurred downstream from Canyon Creek and the North Fork and South Fork Trinity Rivers. It was apparent that streamflows below the North Fork Trinity River were influenced to such an extent by unregulated tributary accretion that management objectives dependent on controlled releases from the TRD would be difficult to achieve. Therefore, after 1987, data collection was focused on the upper river (Segment IA) between Lewiston Dam and Dutch Creek. Enough additional data, however, were collected in the lower river segments to complete hydraulic and habitat modeling in these reaches.

Several successive dry years occurred after 1986, and releases from Lewiston Dam did not vary significantly from those at which data had already been gathered. It was not until 1989 that a release of sufficient magnitude (2,000 cfs) occurred at which data could be collected to expand the capability to estimate habitat availability at higher flows. Very low flows were measured in 1990, a critically dry year, at the 5 sites in Segment IA when 150 cfs was released from the dam. High-flow releases for concurrent, related Trinity River studies of sediment transport and geomorphological processes enabled additional data collection in the later years of the TRFE. Partial data sets were obtained on most transects in Segment IA at flows of 1,500 and 3,000 cfs in 1993, and 4,500 and 6,000 cfs in 1995.

Data were compiled and data decks were constructed as the study progressed. Hydraulic modeling was done for each study site in every segment utilizing, at one time or another, all of the models available within PHABSIM (Gard, 1996, 1997). These reports provide complete hydraulic calibration details. The HABTAE modeling program was used to calculate WUA, combining hydraulic model output with the HSC previously described and presented as digitized indices in Gard (1996, 1997). The suitabilities for the velocity, depth, and substrate variables were combined using standard multiplicative defaults and cell offset averaging.

Physical habitat availability was calculated for the spawning, fry, and juvenile life stages of chinook salmon, coho salmon, and steelhead. In addition, WUA was computed for overwintering juvenile steelhead and holding adult steelhead. Depth and velocity HSC were used in computing WUA for adult steelhead holding and for the fry and juvenile life stages, except for overwintering juvenile steelhead. Substrate criteria were included for them, as well as for spawning for all three anadromous salmonid species. Cover or substrate criteria were not incorporated into WUA computations for the remaining life stages because of lack of observed habitat selectivity for these variables (USFWS, 1987). WUA for Segment IA (Lewiston Dam to Dutch Creek) was derived empirically using directly measured data. Computations were performed using a computer program developed by the Service (Hamilton, 1987). All WUA results for the segments downstream from Segment IA were derived using output from hydraulic simulation models.

> Spawning and rearing habitat varied with stream discharge and species throughout all study reaches.

5.1.2.3 Results for Habitat Availability

Lewiston Dam to Dutch Creek (Segment IA)

Total WUA for spawning salmon and steelhead varied with discharge and species (Figure 5.17A). More physical habitat area was available for spawning chinook salmon than for either coho salmon or steelhead. Maximum habitat was available for all three species at flows between 150 and 350 cfs and decreased steadily as streamflow increased. Adult steelhead holding WUA increased rapidly between 150 and 450 cfs and moderately up to 800 cfs.

The WUA functions for salmon and steelhead fry were very similar to each other over the entire flow range (Figure 5.17B). Chinook salmon and steelhead habitats were available in nearly equal amounts, and these WUA values were consistently greater than values for coho salmon. Fry habitat for all species decreased sharply between 150 and 800 cfs, remained relatively stable to 1,500 cfs, and sharply increased as higher flows inundated the heavily vegetated areas behind the riparian berms and created low-velocity habitat.

The habitat–flow relations for juvenile coho salmon and chinook salmon were similar to those of fry and to each other over the entire range of flows (Figure 5.17C). WUA peaked at 150 cfs, decreased sharply up to a flow of 1,500 cfs, and then increased steadily up to 3,000 cfs. Unlike salmon fry, juvenile WUA was greater at flow levels below about 500 cfs than at flows between 2,000 and 3,000 cfs. Juvenile steelhead WUA peaked at 450 cfs, decreased sharply to 1,500 cfs, and was stable from

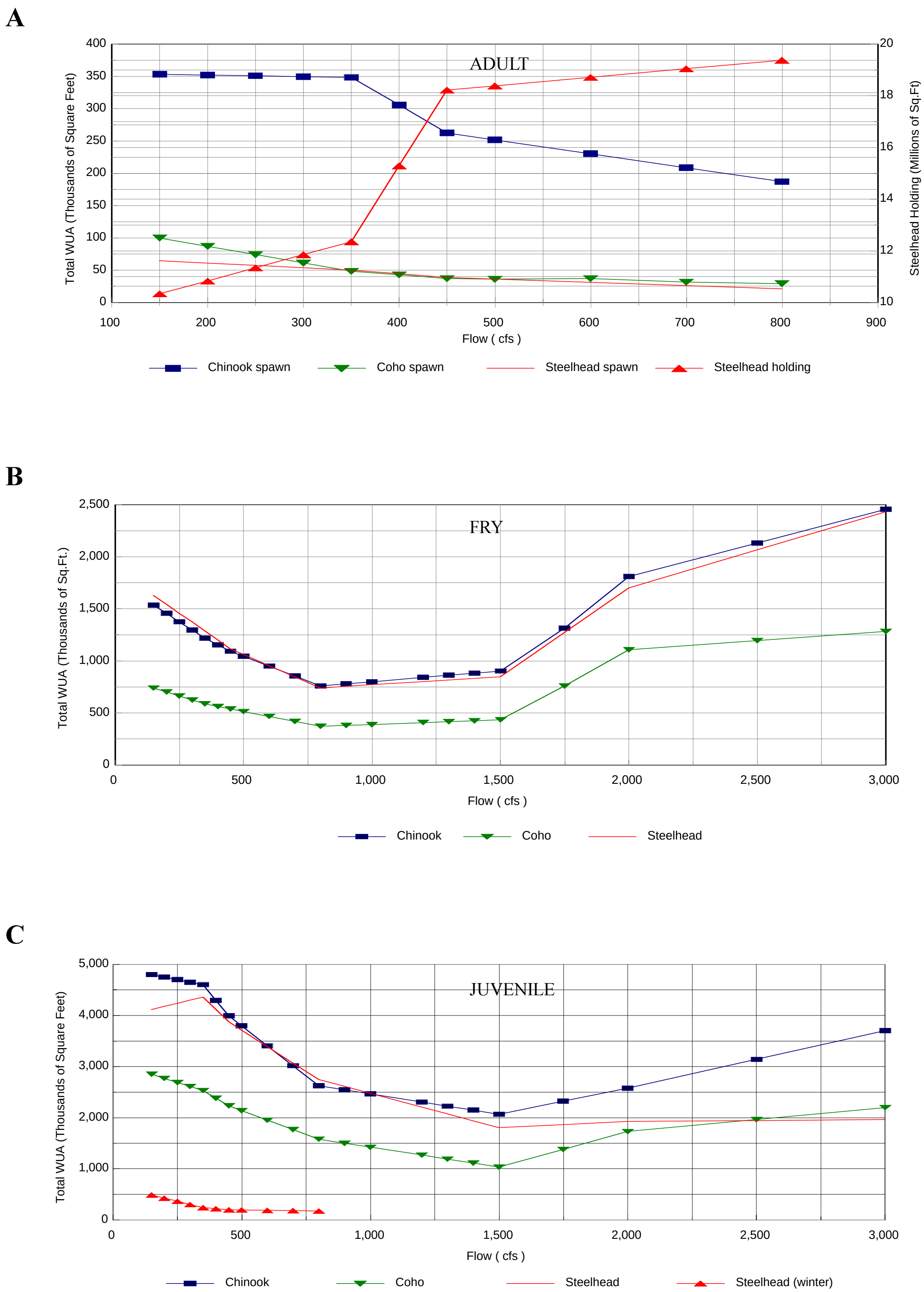


Figure 5.17. Physical habitat for adult (A), fry (B), and juvenile (C) chinook salmon, coho salmon, and steelhead as estimated through direct observation, in Segment IA. Values were derived through direct measurement at 150 cfs, 350 cfs, 450 cfs, 800 cfs, 1,500 cfs, 2,000 cfs, and 3,000 cfs. Habitat estimates between measured flows were interpolated.

1,500 to 3,000 cfs. Overwintering juvenile steelhead habitat values were greatest at the lowest flows measured (150 cfs).

A subset of 10 transects were measured at a flow of 4,500 cfs, allowing computation of WUA for salmonid fry and juveniles up to that flow. These transects, selected on the basis of accessibility, safety, and geographic distribution, represented 24 percent of the total habitat in the segment. Computed WUA was combined with that derived for the same 10 transects at lower flows (Figure 5.18). Results show increases in WUA between 3,000 and 4,500 cfs for fry and juveniles of all three species. The fry and juvenile WUA indices in Segment IA illustrate the pronounced effect of riparian berms on microhabitat. Suitable physical habitat is present in the main channel at low discharges, but it decreases with greater depths and faster velocities at higher flows. Only when the riparian berms are overtopped at increasing flows (1,500 to 2,000 cfs) and the wetted area can increase does suitable habitat area again begin to increase.

Flow-habitat relations for the fry and juvenile life stages were greatly influenced by the existence of the riparian berms in the reach from Lewiston Dam to Dutch Creek.

Dutch Creek to North Fork Trinity River (Segment IB)

The spawning WUA functions in Segment IB were more complex than those observed in Segment IA. Chinook salmon and coho salmon have very similar habitat–flow relations: the habitat values are highest at 150 cfs, but a secondary peak at about 1,200 cfs nearly matches the first (Figure 5.19A). WUA declines after this peak but stabilizes between 1,700 and 2,500 cfs before gradually declining again. Steelhead spawning habitat is available in much lower quantities in this segment, displaying a sinusoidal function that gradually peaks and declines several times over the range of flows evaluated. Steelhead adult holding WUA rises sharply to 450 cfs and then declines sharply as flows increase.

The WUA curves for fry indicate that the effects of riparian berms on habitat characteristic of Segment IA are a lesser factor in Segment IB. Habitat values for all three species are greatest at 150 cfs and generally decline thereafter (Figure 5.19B). Coho salmon fry have the least amount of habitat and steelhead fry the most. The juvenile WUA curves also do not display the strong bimodality of the functions in the upper segment (Figure 5.19C). Chinook salmon and coho salmon habitats peak at 150 cfs and decline, but the decline is very slight over a wide range of flows (700 to 3,000 cfs). Steelhead juvenile WUA increases to 450 cfs and then steadily declines, whereas overwintering juvenile steelhead habitat is very stable over the entire range of simulated flows, peaking at 750 cfs. Overall, Segment IB rearing habitat favors steelhead over chinook salmon over coho salmon.

North Fork Trinity River to South Fork Trinity River (Segment II)

The spawning functions in Segment II were bimodal for all three species (Figure 5.20A). Spawning WUA in the lower end of the flow range peaked at 450 cfs for chinook salmon and 300 cfs for coho salmon and steelhead; the second peak of the function for all three species occurred at a flow of about 2,500 cfs. For the salmon species, these functions represented significantly different habitat–flow relations than those observed in Segment IB, where both WUA peaks occurred at flows at least 50 percent lower than these (Figure 5.19A). The adult steelhead holding function is also very different from those in the previous segments. Holding habitat is very limited at 150 cfs, increasing sharply to a maximum level at about 700 cfs, which is maintained over a wide range of flows up to about 1,700 cfs before declining again gradually.

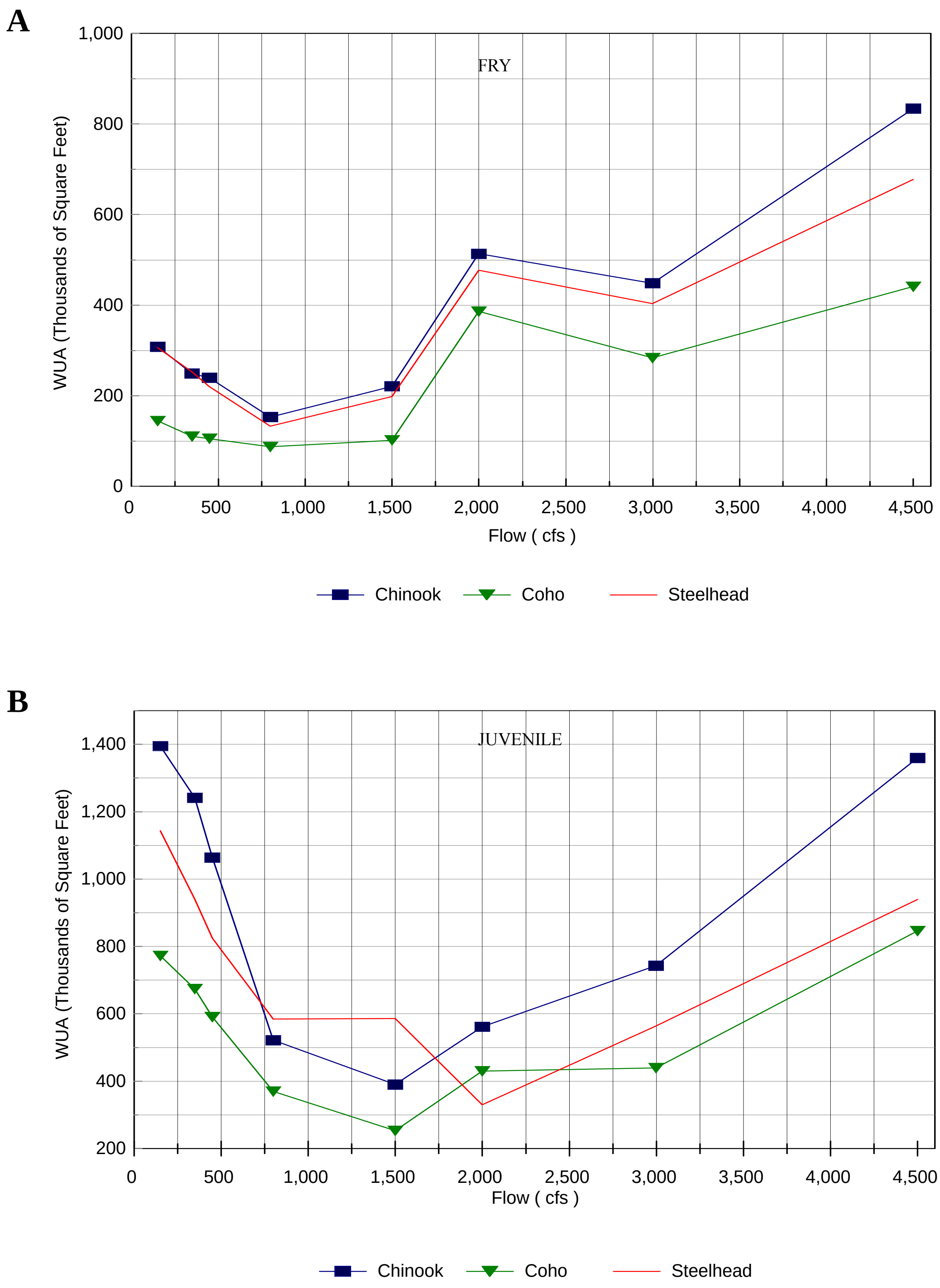
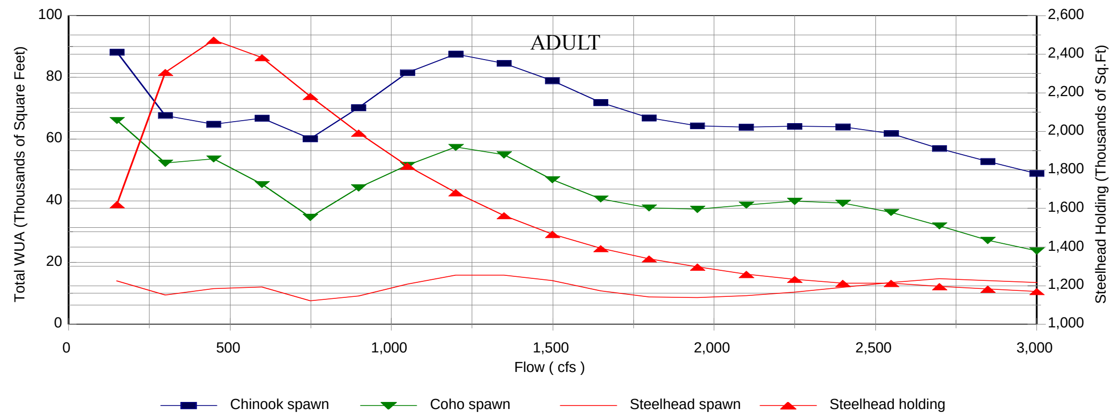


Figure 5.18. Physical habitat availability for fry (A) and juvenile (B) chinook salmon, coho salmon, and steelhead as estimated through direct measurement of a subset of 10 transects representing 24 percent of the total habitat at flows up to 4,500 cfs in Segment IA. Interpolation was used to estimate probable habitat-flow relationships between measured flows.

A



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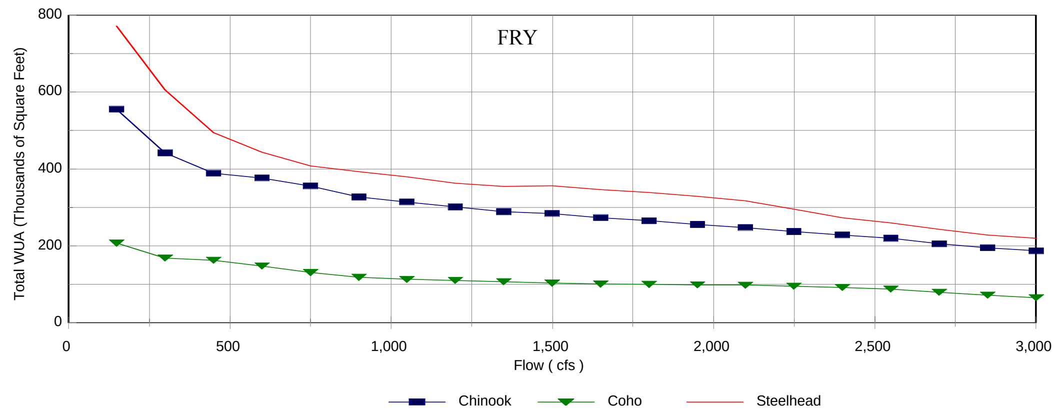

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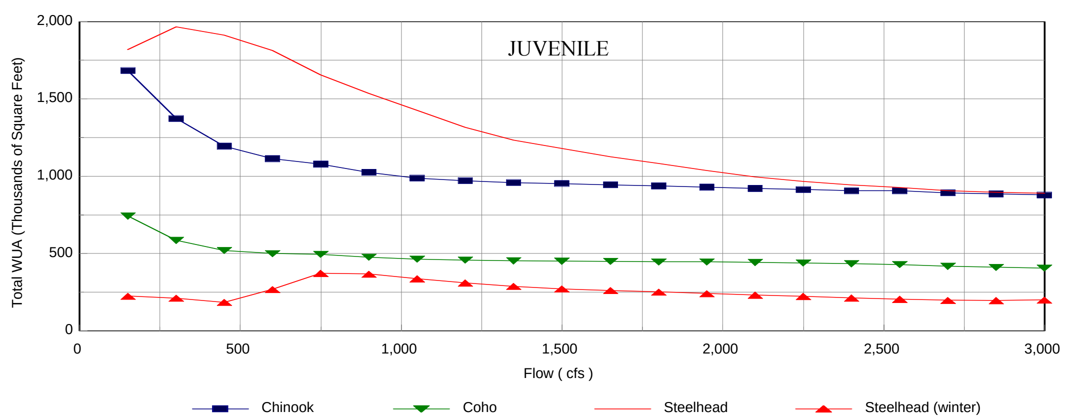


Figure 5.19. Physical habitat availability for adult (A), fry (B), and juvenile (C) salmon and steelhead in Segment IB. Estimates were derived through model simulation.

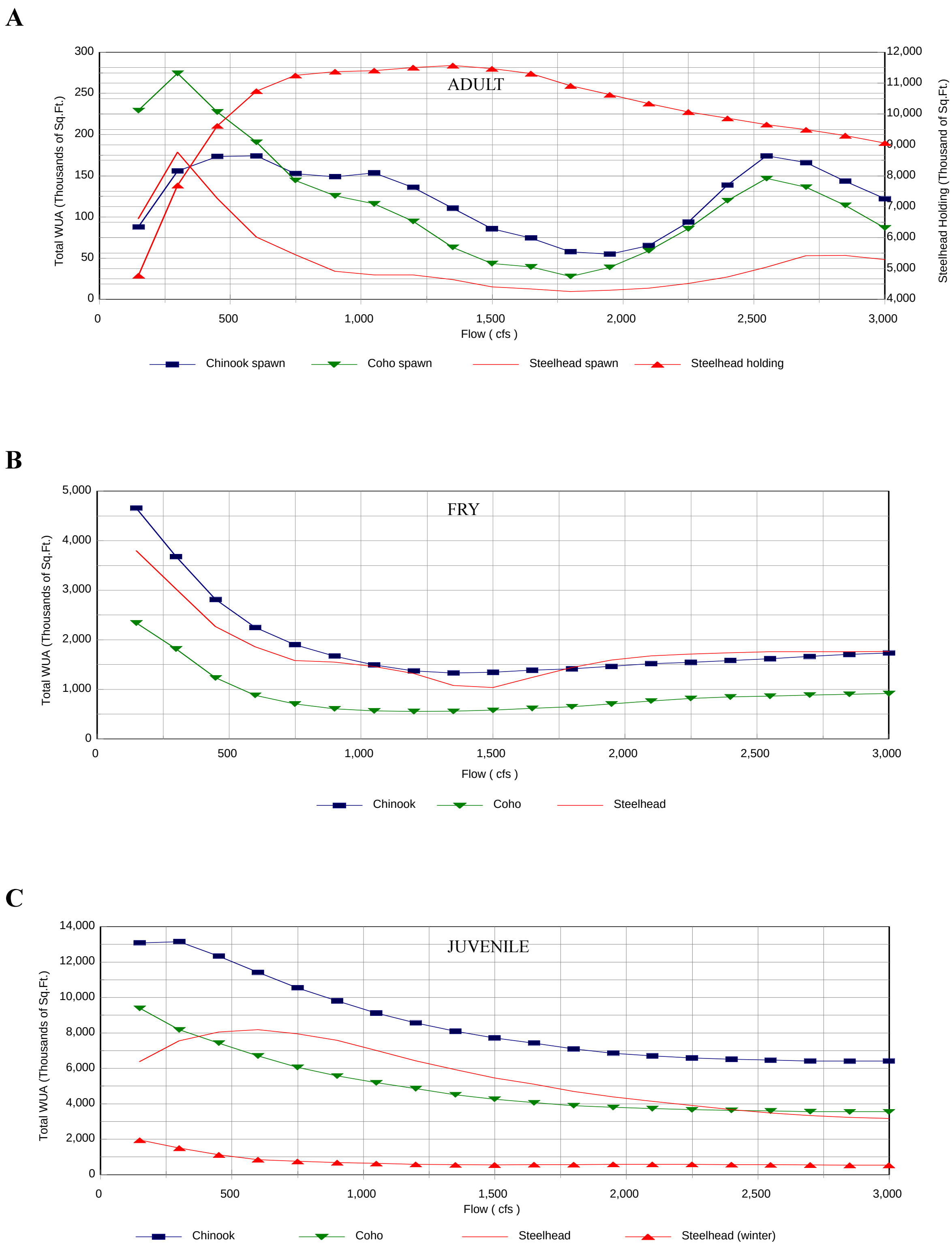


Figure 5.20. Physical habitat availability for adult (A), fry (B), and juvenile (C) salmon and steelhead in Segment II. Estimates were derived through model simulation.

The majority of the WUA curves in Segment II show a reduced influence of riparian berms on channel morphology. Fry WUA was highest at 150 cfs for all three species (Figure 5.20B). The amount of habitat decreased steadily before stabilizing at about 1,000 cfs (chinook salmon and coho salmon) or 1,500 cfs (steelhead); WUA gradually increased as flows increased to 3,000 cfs. Juvenile habitat for chinook salmon and coho salmon was highest at lower flows and decreased steadily (Figure 5.20C). WUA for juvenile steelhead peaked at about 600 cfs. The amount of overwintering steelhead habitat was greatest at 150 cfs and showed about a 50 percent reduction at 600 cfs and greater flows. Overall, the segment favors chinook salmon rearing over coho salmon and steelhead rearing.

<u>South Fork Trinity River to Weitchpec (Segment III)</u>

Spawning habitat availability in Segment III for chinook salmon and coho salmon was greatest at low flows, whereas spawning WUA for steelhead was bimodal, increasing from 150 to 500 cfs and then decreasing to 1,200 cfs before increasing gradually again with flow (Figure 5.21A). Adult steelhead holding WUA was lowest at 150 cfs, climbing sharply to a peak at about 600 cfs and slowly decreasing thereafter to 3,000 cfs.

The WUA curves for Segment III continue to show a reduced influence of riparian berms on channel morphology. The amount of habitat for chinook salmon and coho salmon fry was virtually stable, particularly that for coho salmon (Figure 5.21B). The steelhead fry WUA function had numerous peaks and valleys; flows between 2,000 and 2,500 cfs provided the greatest WUA. For all

Instream flow recommendations for the Trinity River can be made using the results of physical habitat availability modeling in conjunction with information on fish life-history patterns and habitat needs, streamflow patterns (both existing and historical), water-quality variables (such as water temperature), and changing channel morphology.

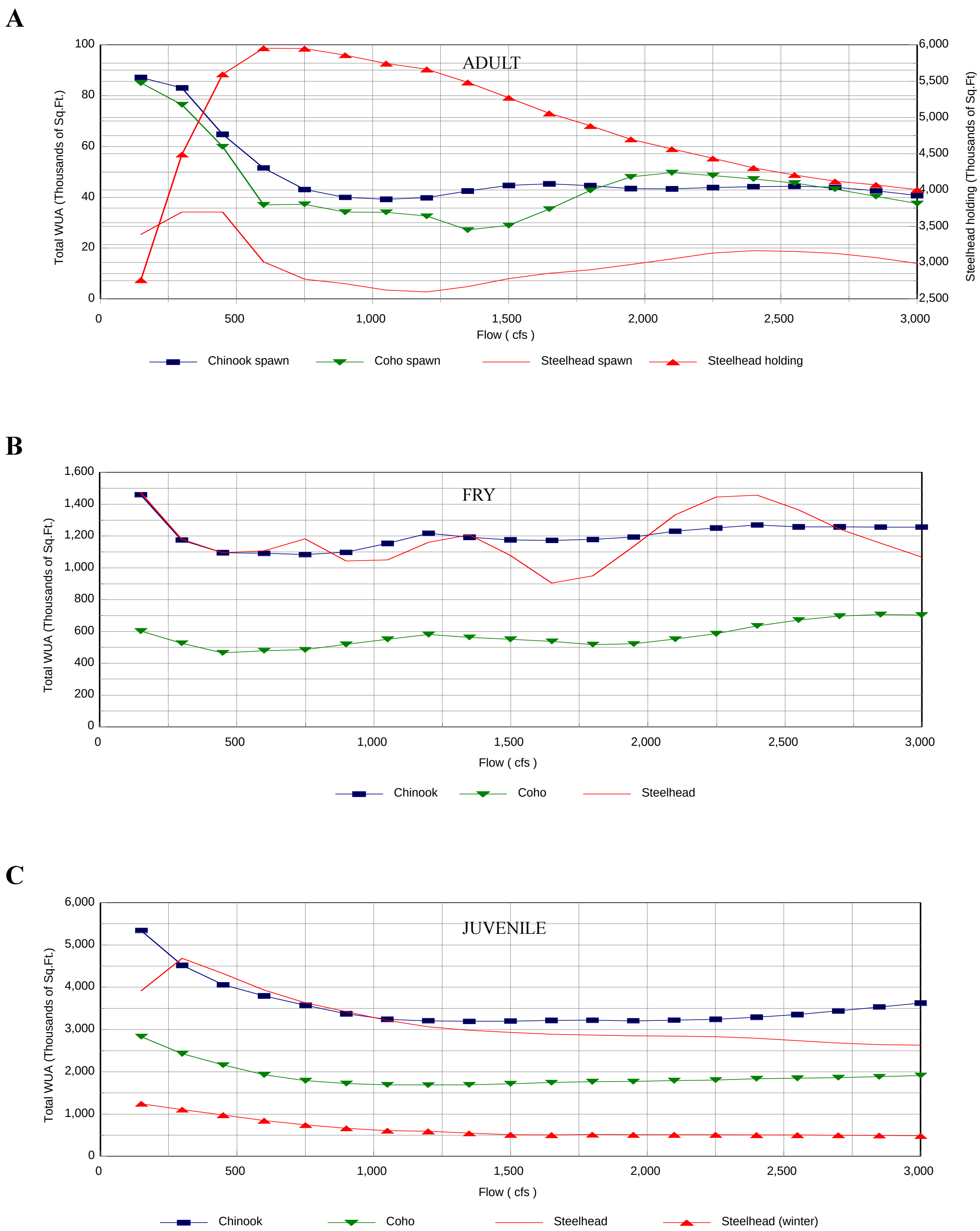


Figure 5.21. Physical habitat availability for adult (A), fry (B), and juvenile (C) salmon and steelhead in Segment III. Estimates were derived through model simulation.

juveniles, WUA curves were almost identical in shape to those in Segment IB (Figure 5.21C). Chinook salmon and coho salmon WUA was greatest at 150 cfs, decreased to about 1,000 cfs, and remained stable thereafter. The juvenile steelhead WUA function peaks at 350 cfs and then declines. Overwintering juvenile steelhead habitat characteristics were identical to those in Segment II.

5.1.2.4 Conclusions

Results of physical habitat availability modeling on the Trinity River are some of the criteria for providing instream flow recommendations and evaluating potential management alternatives. As with any use of PHABSIM habitat modeling, the weighted usable area indices need to be interpreted in the context of fish life-history patterns and habitat needs, streamflow patterns (both existing and historical), water-quality variables (such as water temperature), and changing channel morphology, according to the procedures of the Instream Flow Incremental Methodology.

5.2 Physical Habitat of Bank-Rehabilitation Projects on the Trinity River

5.2.1 Introduction

Monitoring during the initial phases of the TRFE (USFWS, 1988) indicated that the gently sloping point bars of the pre-dam alluvial channel were critical habitat for salmonid fry, which often utilize open, shallow, low-velocity gravel bar habitats (Everest and Chapman, 1972; Hampton, 1988). To rehabilitate the Trinity River, the Service identified as necessary the restoration of the river's historical alternate point bar morphology and the maintenance of this morphology with increased streamflows (USFWS, 1988).

In 1991, the Trinity River Restoration Program initiated a pilot "feathered edge", or bank-rehabilitation program by mechanically removing the riparian berms to reshape portions of the river channel to its historical configuration. From 1991 to 1993, nine pilot bank-rehabilitation projects were constructed by Reclamation and the Service (Table 5.3; Appendix G, Plate 1). Selection of project sites was based on survey data collected by Reclamation and on pre- and post-dam aerial photographs. Additional consideration was given to site access, required excavation volumes, available disposal areas for excavated materials, and land ownership. Projects were constructed along the inside bends of river meanders along historical gravel bar habitats, typically where the post-dam channel confinement had created monotypic run habitats. Heavy equipment was used to remove the riparian berm down to the historical cobble surface, typically 2 to 3 feet below the water-surface elevation associated with a 300-cfs dam release (Gilroy, 1997, pers. comm.), and to reshape the bank. The opposite bank of each site was left undisturbed. Project sites ranged from 395 to 1,200 feet in length.

To evaluate the effectiveness of the bank-rehabilitation projects in providing increased salmonid fry rearing habitat, the Service initiated microhabitat assessments of the pilot bank-rehabilitation projects.

Construction and operation of the TRD resulted in a change in channel morphology from one of gently sloping point bars to a narrow trapezoidal channel contained within steep riparian berms. This change in channel morphology eliminated most of the gently sloping point bars of the pre-dam alluvial channel that provided open, shallow, low-velocity gravel bar habitats for rearing salmonid fry. Restoration and maintenance of the fishery resources of the Trinity River requires, in part, rehabilitation of the channel morphology in the mainstem below Lewiston Dam similar to that of the pre-TRD channel morphology.

Table 5.3. Channel-rehabilitation project sites on the mainstem Trinity River.

Site	River Mile	Construction Date
Bucktail	105.6	1993
Limekiln	100.2	1993
Steel Bridge	98.8	1993
Steiner Flat	91.8	1991-1993
Bell Gulch	84.0	1993
Deep Gulch	82.2	1993
Sheridan Creek	82.0	1993
Jim Smith	78.5	1993
Pear Tree Gulch	73.1	1992

5.2.2 Methods

Two salmonid rearing habitat assessments of the bank-rehabilitation projects were conducted using PHABSIM (Bovee, 1982). PHABSIM was used to relate changes in stream discharge to changes in WUA. The first habitat assessment was a site-specific comparison of pre- and post-rehabilitation habitat for chinook salmon fry. Pre-rehabilitation WUA indices were available for two bank-rehabilitation sites: Steel Bridge (RM 98.8) and Steiner Flat (RM 91.8). Post-construction WUA indices for these same sites were computed using PHABSIM data collected in 1995 (USFWS, 1996).

The second habitat assessment evaluated the effect of bank-rehabilitation on the chinook salmon fry flow–habitat relations for a generalized bank-rehabilitation project. Three of the nine sites, Bucktail (RM 105.6), Steiner Flat (RM 91.8), and Sheridan Creek (RM 82.0), created shallow, low-velocity salmonid habitat (Appendix G, Plates 3 and 4). These sites contained characteristics similar to those of natural gravel bars, mid-channel bars, backwaters, and other features typical of unregulated riverine systems (McBain and Trush, 1997). WUA indices were computed for a combination of 15 transects (3 from the Bucktail site, 7 from the Steiner Flat site, and 5 from the Sheridan Creek site) (USFWS, 1997). WUA indices were computed for the non-rehabilitated channel from data collected at 11 transects (equally weighted) representing run habitats from the Bucktail (4 transects) and Steiner Flat (7 transects) study sites in 1985, 1986, 1989, and 1990 (USFWS, 1997). Run-habitat transects at the Bucktail and Steiner Flat sites were

Proper design and construction of channel-rehabilitation projects increases salmonid rearing habitat. Rehabilitation of the Steel Bridge site had little effect on chinook salmon fry rearing habitat at low flows and it decreased chinook salmon fry rearing habitat at moderate to high flows. At the rehabilitated Steiner Flat site, chinook salmon fry rearing habitat was increased at all flows.

selected to represent the non-rehabilitated channel because the bank-rehabilitation sites were run habitats prior to construction (Gallagher, 1995) and because these sites were in close proximity to the representative bank-rehabilitation sites.

The absolute reliability of the WUA indices was limited by the relatively small number of appropriate transects, the narrow flow range for hydraulic modeling, and the uncertainty regarding the ultimate configuration of the rehabilitated sites and the adjacent reaches of the river. WUA indices for fry and juvenile chinook salmon, coho salmon, and steelhead were computed for a rehabilitated channel and the non-rehabilitated channel. For this report, data for only chinook salmon are presented: data for coho salmon and steelhead indicated similar trends in flow–habitat relations in the rehabilitated and non-rehabilitated channel (USFWS, 1997). Because of the differences in locations of transects representing the rehabilitated and non-rehabilitated channel, direct comparisons of the magnitude of the flow–habitat relations were not possible. The data were used to assess the changes in the WUA flow–habitat relation as a result of bank rehabilitation.

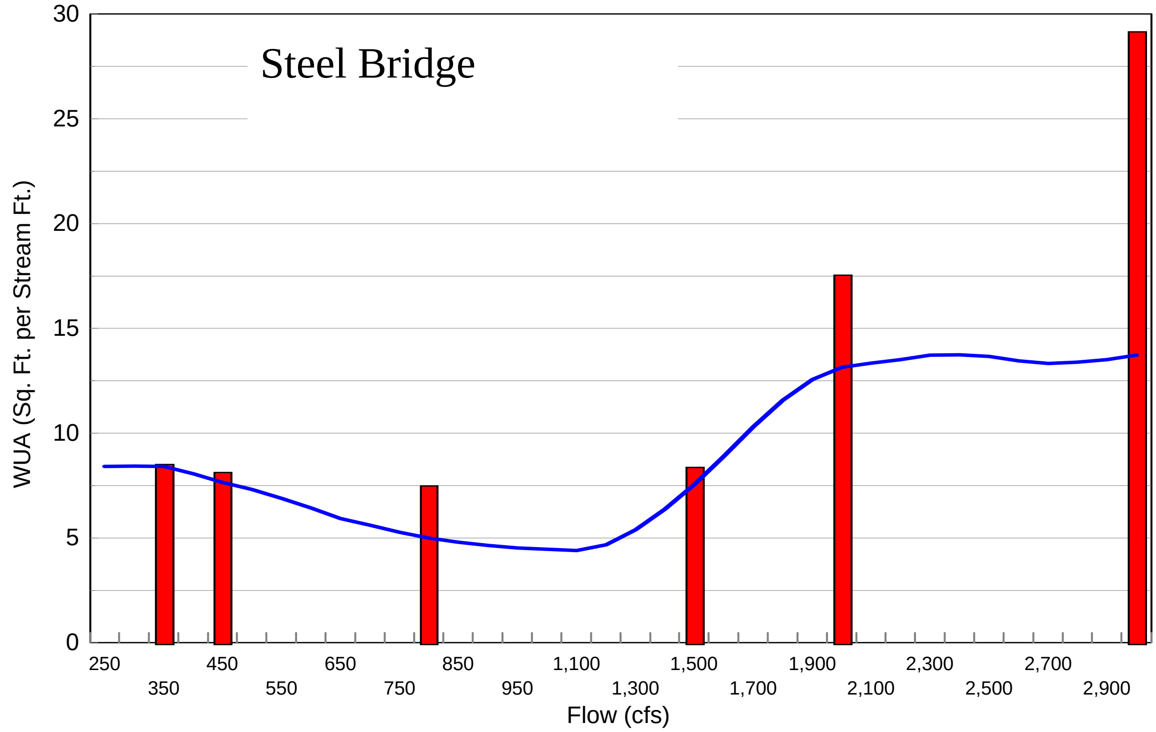
As flows change, the amount of salmonid fry rearing habitat in the existing channel varies greatly, whereas in the rehabilitated channel the amount of rearing habitat was relatively stable.

5.2.3 Results

Site-specific comparisons of the chinook salmon fry WUA before and after construction of the Steel Bridge and Steiner Flat sites showed variable results. Rehabilitation of the Steel Bridge site had little effect on chinook salmon fry WUA at low flows (≤450 cfs), and it decreased chinook salmon fry rearing habitat at higher flows (>450 cfs) (Figure 5.22). At the rehabilitated Steiner Flat site, chinook salmon fry WUA was increased throughout the range of flows studied (Figure 5.22).

In the non-rehabilitated channel, the largest WUA values for fry and juvenile chinook salmon occurred at the lowest and highest flows (Figures 5.23A, 5.23C). As flows increased to approximately 1,500 cfs, water velocities and depths increased to levels that were less suitable for rearing salmonids. However, as flows increased above approximately 1,500 cfs, the areas behind the riparian berms became inundated and suitable depths and velocities were again available. The high WUA values at the lowest flows (150 cfs) were derived primarily from large areas of poor habitat (Composite Suitability Value <0.20) over a broad area. The greatest variability in WUA in the non-rehabilitated channel occurred for the fry life stage.

In contrast, WUA values for the rehabilitated channel were relatively stable throughout the range of flows modeled (Figures 5.23B, 5.23D). Chinook salmon fry WUA varied little throughout the range of flows modeled. Juvenile WUA initially decreased as flow increased from 150 cfs to approximately 750 cfs, and then gradually increased to levels equal to those at the lowest flows.



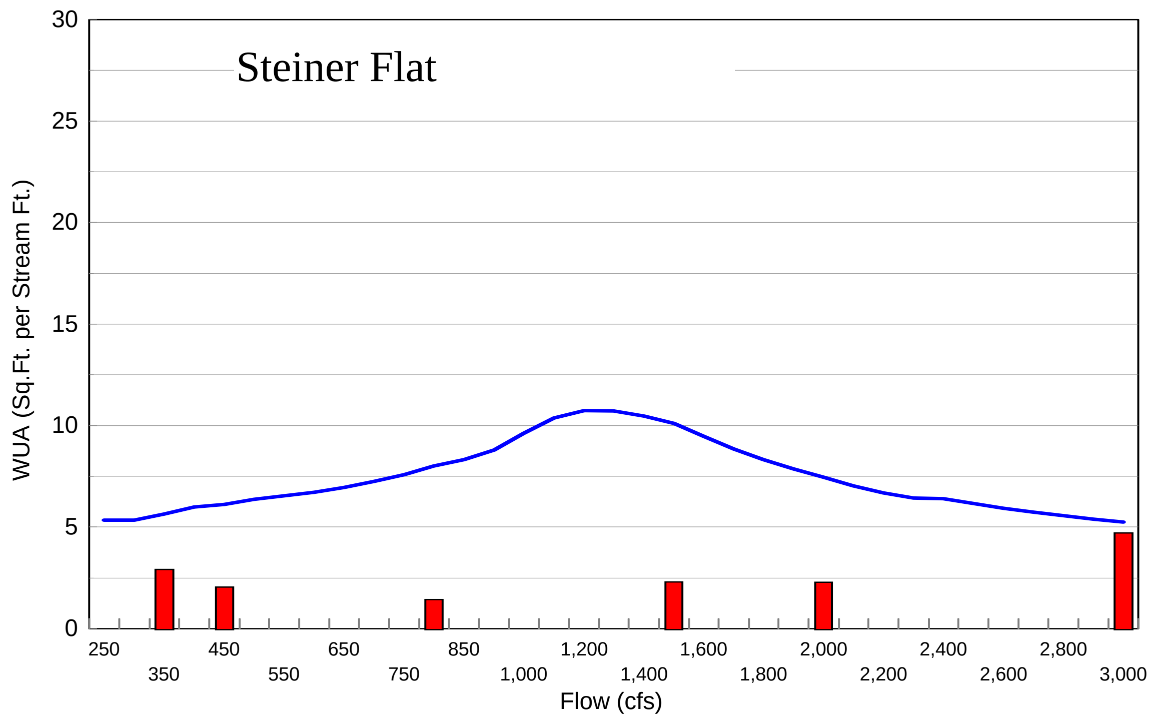


Figure 5.22. Comparison of chinook fry habitat before (bars) and after (line) construction of Steel Bridge (RM 98.8) and Steiner Flat (RM 91.8) bank-rehabilitation projects. Habitat estimates for "before" conditions were derived from direct measurement. Habitat estimates for "after" conditions were derived through modeling.

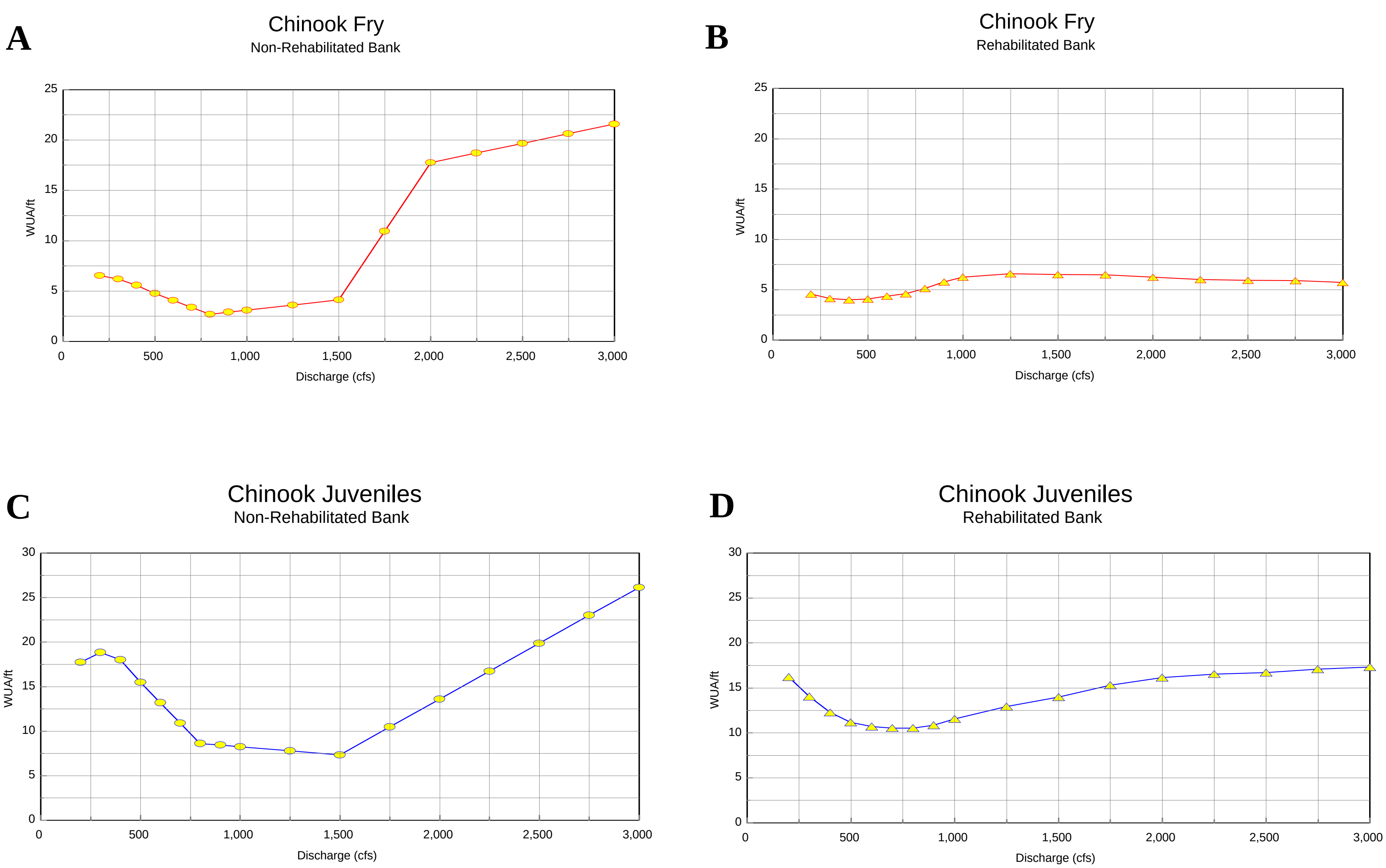


Figure 5.23. Flow-habitat relations for fry and juvenile chinook salmon with non-rehabilitated and rehabilitated banks, Trinity River.

5.2.4 Conclusions

> Implementing channel-rehabilitation projects allows for a broadening and gradual sloping of the narrow trapezoidal channel, which allows the river flows to spread out and water velocities to decrease. This provides suitable depths and velocities for rearing salmonids regardless of flow magnitude, and because the river often experiences substantial changes in flow during winter storms, providing suitable habitat throughout a wide range of flows is necessary to prevent habitat bottlenecks.

Assessments of salmonid rearing habitat before and after bank rehabilitation indicate that, when properly designed and constructed, these projects can increase salmonid fry rearing habitat (Figure 5.22). The importance of project design and construction was exemplified by the Steel Bridge site, where the project failed to increase salmonid rearing habitat (Figure 5.22). The lack of a beneficial response was attributed to the morphological characteristics of the site. The rehabilitation of the bank resulted in a steep bank that did not provide shallow, low-velocity habitat when flow increased. In contrast to the Steel Bridge site, removal of the riparian berms and recreation of gently sloping point bars at the Steiner Flat site increased rearing habitat throughout the range of flows studied. Prior to construction of the Steiner Flat bank-rehabilitation project, the river at this site was a long, channelized run that provided little rearing habitat.

Comparison of the flow-habitat relations of the existing channel and a generalized bank-rehabilitation project indicated that bank rehabilitation had a positive effect on the flow–habitat relation. The restoration of gently sloping gravel bars changed the flow–habitat relation, from one in which there was great variability in habitat availability between low and high flows to one in which habitat availability was relatively stable throughout the range of flows studied (Figures 5.23B, 5.23D). In the non-rehabilitated channel, the large variability in habitat availability throughout the range of flows was due to the trapezoidal configuration of the channel (Figures 5.23A, 5.23C).

The broadening and gradual sloping of the narrow trapezoidal channel allowed the river flows to spread out and water velocities to decrease, providing suitable depths and velocities for rearing salmonids regardless of flow magnitude (Figures 5.23B, 5.23D). Bands of suitable habitat along the stream margin were relatively consistent at all flows and migrated up and down the gently sloping bank relative to changes in flow (Figure 5.24).

Because the river often experiences substantial changes in flow during winter storms, providing suitable habitat through-out a wide range of flows is necessary to prevent habitat bottlenecks.

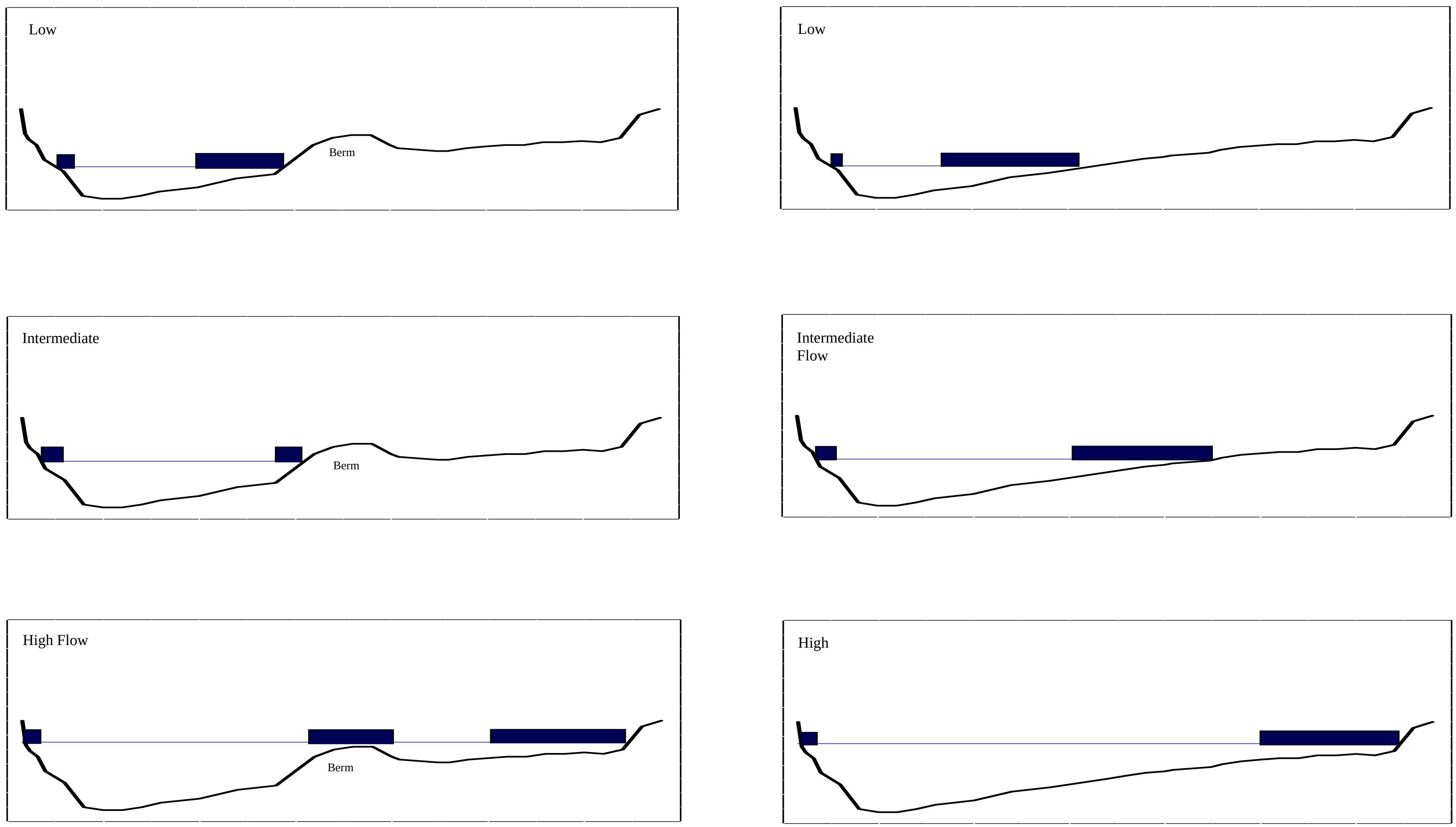


Figure 5.24. Representation of the existing channel with the riparian berm and the rehabilitated channel with salmonid fry rearing habitat (represented by the boxes) at low, intermediate, and high flows.

Evaluation of the pilot bank-rehabilitation projects indicated that, when properly constructed, bank rehabilitation can effectively increase the amount of salmonid fry rearing habitat in the mainstem Trinity River.

Habitat stability throughout the rearing period is crucial to the survival of young salmonids, especially fry that are particularly vulnerable to rapid and significant habitat changes (Healey, 1991; Sandercock, 1991). In the rehabilitated channel, stable amounts of suitable rearing habitat are maintained as flows change, in distinct contrast to the pattern evident in the non-rehabilitated channel.

Channel-rehabilitation projects will have the additional benefit of reducing salmonid fry stranding that is exacerbated by the presence of riparian berms (Zedonis, pers. comm; Aguilar, 1997, pers. comm.). When safety of dam releases exceed ~1,500-2,000 cfs, which typically occur during the chinook fry lifestages, the areas behind the riparian berms are inundated, creating slow water areas. Salmonid fry, seeking refuge from high velocities, move into these slow water zones behind the riparian berms and become isolated from the mainstem as flows are reduced. Channel rehabilitation will lessen the effects of high flow on fry stranding by eliminating the riparian berms and providing consistent amounts of contiguous habitat over a wider range of flows.

5.2.5 Recommendations

Rehabilitation of degraded salmonid rearing habitat requires reforming the existing channel to one that resembles the pre-TRD channel. Evaluation of the pilot bank-rehabilitation projects indicated that, when properly constructed, bank rehabilitation can effectively increase the amount of salmonid fry rearing habitat in the mainstem Trinity River. In addition to providing shallow, low-velocity habitat for rearing salmonid fry, these projects provide habitat stability over a wide range of flows.

5.3 Fine Sediment Transport and Spawning-Gravel Flushing

5.3.1 Introduction

Wilcock et al. (1995) investigated a fine sediment flushing flow that could (1) maximize the removal of fine-grained sediment (particles finer than $^{5}/_{16}$ inch) stored in the mainstem Trinity River from the Grass Valley Creek confluence (RM 104.0) downstream to the BLM Steel Bridge Campground (RM 99.0); (2) minimize water needed for fine bedload transport; (3) minimize downstream gravel loss; and (4) provide gravel entrainment sufficient to permit fine sediment removal from the channelbed to a depth typically excavated in redd construction. Wilcock et al. (1995) hypothesized that if planned dam releases could just mobilize the spawning-gravel substrate, fine sediment in gravel interstices would be exposed to fluid forces and transported downstream whereas gravel loss would be minimal. Once fine sediment in the channelbed was mobilized, this fine sediment would be deposited on floodplains, removed by dredging (assuming a maximum total annual instream volume of 340 TAF), or eventually transported from the study reach.

5.3.2 Methods

Two mainstem sites with abundant spawning-gravel deposits, simple hydraulic characteristics at high flows, and convenient access were investigated (Figure 5.25): Poker Bar (RM 102.4), 1.6 miles downstream from Grass Valley Creek; and Steel Bridge (RM 99.0), 5.0 miles downstream from Grass Valley Creek. The Steel Bridge site consisted of two mainstem channels separated by a densely wooded island that likely was once a mobile medial bar before TRD operations. In addition to these

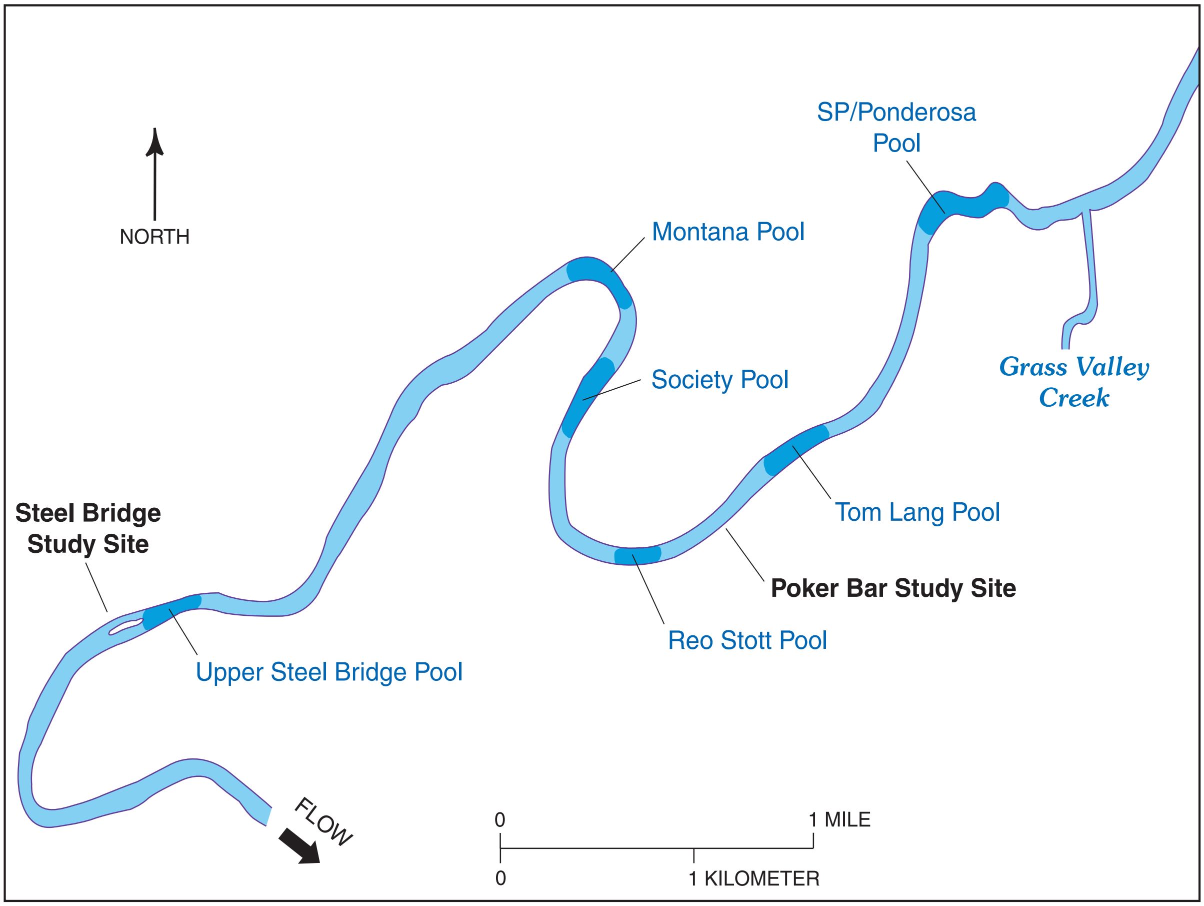


Figure 5.25. Study area showing study sites and pool locations.

sites, five pools were chosen to quantify anticipated changes in fine sediment storage following experimental flow releases.

Three dam releases were investigated. The WY1991 flow release extended 6 days, from May 28 to June 2, with a daily maximum release between 2,600 cfs and 2,800 cfs from May 29 to June 1. From May 30 to June 1 the discharge measured at the study site was a relatively constant 2,670 cfs. In WY1992 the flow release extended 10 days from June 10 to June 19. A relatively constant discharge of 5,800 cfs was observed at the study sites from June 13 to June 16. The WY1993 flow release, lasting 22 days from April 13 to May 4, narrowly fluctuated around 3,000 cfs from April 14 to April 30.

Excavated pits filled with marked tracer gravels documented gravel entrainment by dam releases at both study sites. Following a dam release, the number and size of tracers remaining in the pit were recorded, as well as the distance mobilized tracers were displaced. Net scour or fill at each tracer pit was measured by comparing channelbed elevation before and after a release. Comparison of the pre- and post-release elevations of the marked tracers yielded a measurement of scour depth and subsequent fill in the tracer pit.

To estimate the flow threshold for gravel entrainment, the exchange depth, d_{ex} (defined as the total depth of tracer gravels multiplied by the proportion of gravels entrained) was compared with the surface D_{90} (the 90th percentile rock diameter) for each dam release. The surface D_{90} diameter defined the thickness of the channelbed's

Fine sediment reduces salmonid production by infiltrating spawning gravels and increasing egg and alevin mortality, depositing on exposed cobble bar surfaces and reducing salmonid fry and over-wintering rearing habitat, and in extreme cases, filling pools and reducing adult holding habitat. Reducing fine sediments in the mainstem Trinity River, particularly decomposed granitic sands, will greatly improve salmon habitat and salmon production.

coarse surface layer. Peak flows resulting in values of d_{ex}/D_{90} close to 1 represented a minimum flow threshold for gravel entrainment. Pebble counts (Wolman, 1954) were conducted to characterize surficial particle-size distributions before and after experimental releases. Subsurface bulk samples, collected before and after dam releases, characterized changes in particle-size distribution of the bed material to measure potential reductions in fine sediment (less than $^5/_{16}$ inch) accumulation attributable to the experimental releases.

Bedload transport rates were measured two ways: by Helley-Smith sampling from a cataraft and by means of bedload boxes placed in the streambed to catch mobilized bedload (refer to Wilcock et al., 1995, for sampling details). Samples collected with the Helley-Smith sampler were weighed and analyzed for particle-size distribution and bedload transport rate (tons/day). Bedload boxes were periodically cleaned by a diver during the dam release to prevent overfilling. The amount of trapped bed material and the time interval between box cleanings were converted to a bedload transport rate. Sediment rating curves were developed for sand and gravel.

Sixty-five hundred cfs mobilized the bed surface particles, but did not scour the bed surface greater than a D_{90} depth; 3,000 cfs neither mobilized the bed surface particles nor cause bed scour.

From a cataraft, fine sediment storage in the upper 0.5 foot of the entire channelbed was mapped onto aerial photographs for the reach of the mainstem from the Grass Valley Creek confluence to the Steel Bridge Campground. The top 0.5 foot was assumed to be the depth at which flushing flows could scour and redeposit the bed surface. For the top 0.25 foot of the channelbed surface, a percentage of fine surficial sediment was visually estimated. For the underlying 0.25 foot, a constant percentage of 25 percent (based on bulk sampling at the Poker Bar site) was used. In the five study pools, bathymetric surveys quantified net changes in fine sediment storage between dam releases and were used to estimate pool trapping efficiency (refer to Wilcock et al., 1995, for details).

The methodologies adopted by Wilcock et al. (1995) were based on three primary assumptions: (1) that the two study sites chosen for quantifying surface bed mobility, bed scour, and bedload transport rates represented most of the degraded reaches of the Trinity River; (2) that Grass Valley Creek would continue to supply fine sediment to the Trinity River mainstem; and (3) that a fixed annual volume of water (340 TAF) would be available for flushing flows and meeting fishery flow needs. An unstated assumption was that pool dredging was the most practicable means to reduce the volume of fine sediment in the reach because the necessary annual peak flow duration needed to remove all fine sediment required too much water.

5.3.3 Results

WY1991 (2,600 cfs) and WY1993 (3,000 cfs) peak releases did not significantly entrain underlying finer sediment in spawning-gravel deposits at either the Poker Bar study site or Steel Bridge study site (i.e., d_{ex}/D_{90} was less than 1). Sand was removed only from interstitial spaces at the channelbed surface. The WY1992 dam release (6,500 cfs), "was just sufficient to mobilize the surface gravel layer and entrain underlying finer sediment" (Wilcock et al., 1995, p. 87). For example, scour depths for three tracer gravel cores at cross section Poker Bar #2 were 3 $^{15}/_{16}$ to 5 $^{1}/_{8}$ inches, which was greater than the surface D_{90} depth.

> High flow releases between 2,700 cfs and 6,500 cfs reduced surficial in-channel fine sediment storage, but not subsurface sand storage.

At the Poker Bar site, the median particle size of the subsurface bed material was $^{7}/_{8}$ inch, with 30 percent of particles finer than $^{5}/_{16}$ inch. Because the WY1991 experimental release did not mobilize the bed surface layer, the release did not significantly modify the subsurface composition. Scour depth was less than 1 $^{9}/_{16}$ inches for all five scour cores at Poker Bar, and less than 2 inches for all Steel Bridge scour cores. As previously stated, channelbed scour was substantially deeper at the Poker Bar site during the WY1992 release; surface grains from all gravel size classes were transported. Scour depths for three tracer gravel cores at Poker Bar were 3 $^{15}/_{16}$ to 5 $^{1}/_{8}$ inches, which exceeded the D_{90}. Pebble counts and bulk samples indicated no significant changes in the proportion of fine sediment resulting from the WY1992 release. The WY1993 release produced results similar to those of the WY1991 release, although flow duration was considerably longer. Similar results were recorded at the Steel Bridge Campground site for the three releases.

> Fine sediment transport and spawning gravel flushing recommendations:
>
> - 5-day release of 6,000 cfs to mobilize gravel-bed surface and maximize fine sediment transport;
> - maximize fine sediment trapping efficiency in upper Trinity River by increasing pool volume in six pools immediately downstream of Grass Valley Creek;
> - periodically dredge these six pools to reduce in-channel fine sediment storage.

Bedload boxes placed at Poker Bar during the WY1993 flow sampled a bedload transport rate of 0.023 tons/day for sediment coarser than $^{5}/_{16}$ inch. Sand bedload (finer than $^{5}/_{16}$ inch) transport rates, in tons per day, were 112,400; 223,600; and 34,400 for WY1991, WY1992, and WY1993 peak releases, respectively. Refer to Wilcock et al. (1995) for details of gravel transport model and sediment rating curves.

Prior to the WY1992 flow, weighted reach values of percent coverage by fine sediment (< $^{5}/_{16}$ inch) varied from 13.6 to 43.5 percent. Following the WY1993 flow, weighted reach values of percent coverage by fine sediment varied from 13.4 to 27.6 percent, which represented a substantial reduction of in-channel sand storage. However, the WY1992 release, "did not produce a substantial reduction in the proportion of fine materials in the bed. To achieve successful flushing at depth, the total volume of sand in the reach must be reduced." (Wilcock et al., 1995).

The repeat bathymetric pool surveys detected net volume changes in each monitored pool for WY1991, WY1992, and WY1993 experimental releases, respectively, as follows: Reo Stott pool, –129 yd^3, +487 yd^3, and –414 yd^3; Society pool, +160 yd^3, +1,874 yd^3, and –77 yd^3. For WY1992 and WY1993 only, net volume changes for other monitored pools were: Tom Lang pool, +885 yd^3, -1,038 yd^3; Upper Steel Bridge pool, -167 yd^3, -551 yd^3; SP/Ponderosa, -516 yd^3, -1,095 yd^3.

5.3.4 Conclusions

The WY1992 release of 5,800 cfs for 5 days was just sufficient to mobilize the surface layer of gravel and scour the underlying sediment, although no significant decrease in fine sediment was observed. On the basis of this finding, Wilcock et al. (1995) recommended a flushing release of 6,000 cfs for 5 days. Their flushing release schedule and recommendation for continued dredging were tailored around the assumption that only 340 TAF was available for instream releases (Wilcock, pers. comm., 1997). Given more water, sand transport could be improved by holding a given release level longer or increasing the magnitude within the given duration. For example, Wilcock et al. (1995) stated, "A sediment maintenance release need not use a constant discharge. One alternative is to use a short, large discharge to efficiently accomplish full bed surface mobilization, followed by a longer release at a low discharge to accomplish additional sand removal with little additional gravel loss."

The process of removing fine sediment from the reach is different from that of flushing fine sediment from gravels: flushing flows expose and transport fine sediment but do not necessarily remove it all from the river system. Wilcock et al. (1995) used flushing flows to transport fine sediment to local pools, where it would be trapped and periodically dredged. Four pools between Grass Valley Creek and Steel Bridge have been dredged; the authors recommended that two additional pools be added between Society Pool (RM 101.3) and Steel Bridge Campground (RM 99.0) because this reach is the longest without pools and has the greatest instream sand storage.

Trap efficiency is a function of local hydraulics through a pool, which in turn is related to the dimensions (width, length, and depth) of the pool. The recommended flushing flow, based on Wilcock's calculations, that maximizes pool trapping efficiency is from 5,000 to 6,000 cfs. Wilcock et al. (1995) found that at discharges between 5,000 and 6,000 cfs, pool trap efficiency can be optimized by dredging the pool 2 feet below the stable pool depth. Because this 5,000 to 6,000-cfs flow just begins to mobilize the gravel bed surface, bedload transport is minimized and sand transport is large. Dredging deeper could trap a greater volume of fine sediment transported by higher and (or) longer discharges.

> Fluvial geomorphic processes underpin the structure and function of complex river ecosystems. Restoring salmonid habitat (and populations) must be underpinned by restoring fundamental fluvial geomorphic processes.

5.4 Fluvial Geomorphology

The decline in the Trinity River salmonid fishery is directly correlated with the dramatic change in the geomorphologic character of the basin since construction of TRD. Chapter 3 describes the general habitat requirements and abundance trends for the fishery resources of the Trinity River and concludes that diverse habitats are needed to support the various life stages of the fish. Post-TRD changes in flows and sediment budgets have caused the habitats to become less diverse, leading to the decline in fish populations.

Fluvial geomorphologic processes underpin the structure and function of complex river ecosystems. To restore habitat diversity will require restoring natural geomorphologic processes within contemporary sediment supply and flow limitations. The alluvial attributes described in Section 4.8 provide a framework upon which initial hypotheses can be formulated relating unregulated (natural) flow regimes with important physical and ecological processes. Understanding these processes, and how they have changed because of TRD, provides insight into how they might be used to restore key components of the river ecosystem.

This section integrates geomorphologic studies into those physical and ecological processes. Examining historical flow data provides insight into needed flow variability (Section 4.8, Attribute No. 2). Measuring contemporary channelbed hydraulics provides data regarding the flows needed to cause both incipient channelbed mobility and significant scour and fill (Section 4.8, Attributes No. 3 and No. 4). Understanding fine and coarse sediment budgets provides information needed to manage sediment inputs to provide the desired geomorphologic response (Section 4.8, Attribute No. 5). Studying processes leading to riparian encroachment provides insights into how encroachment can be managed (Section 4.8, Attribute No. 9).

> Salmonids and other native riverine organisms evolved under a variable streamflow regime; water year classification describes inter-annual streamflow variability, and annual hydrograph components provide intra-annual streamflow variability.

5.4.1 Flow Variability

Flow variability within the Trinity River basin was assessed by examining historical data collected at three USGS gaging stations, and more recent data collected at five gages established and operated by the Hoopa Valley Tribe. Gage locations and periods of record are provided in Table 4.2.

5.4.1.1 Water-Year Classification

A water-year classification system for the Trinity River basin was developed by evaluating annual basin water yield for the watershed upstream from the Lewiston gage. For water years prior to TRD construction (WY1912 to WY1960), flow records from the USGS Trinity River at Lewiston gaging station were used to quantify annual basin water yield. For water years after TRD construction (WY1961 to WY1995), estimates of flows into Trinity Lake prepared by Reclamation were used. Individual annual basin water yields were ranked and the exceedence probability (*p*) calculated. A plot of the data is shown in Figure 5.26. Five water-year classes were delineated. Extremely Wet years have $p \leq 0.12$ and produce annual basin water yields greater than 2,000 TAF. Wet water years have $0.12 < p \leq 0.40$ and produce annual basin water yields between 2,000 and 1,350 TAF. Normal water years have $0.40 < p \leq 0.60$ and produce annual basin water yields between 1,350 and 1,025 TAF. Dry water years have $0.60 < p \leq 0.88$ and produce annual basin water yields between 1,025 and 650 TAF. Finally, Critically Dry water years have $p > 0.88$ and produce annual water yields less than 650 TAF.

5.4.1.2 Annual Hydrograph Components

Seasonal patterns of average daily flow for rivers in the Pacific Northwest consist of winter floods, winter baseflows, snowmelt peak runoff, snowmelt recession, and summer baseflows. These components are illustrated in Figure 4.10. Hydrograph components for various locations in the basin were characterized by duration, magnitude, frequency, seasonal timing, and inter-annual variability. Peak snowmelt runoff and high summer baseflows dominate annual hydrographs for sub-basins upstream from Lewiston, whereas for sub-basins downstream from Lewiston winter rainfall runoff and relatively low summer baseflows dominate. These differences have significant geomorphologic and ecological consequences.

Winter floods are either rainfall or rain-on-snow events that typically occur between mid-November and late March. Peak flows exceeding 70,000 cfs have occurred three times since WY1912. The magnitude of peak flows is generally correlated with water-year classification, with Extremely Wet water years producing bigger floods. An exception is the December 1964 flood that peaked above 100,000 cfs but occurred during a Wet water year. Floods at Lewiston have been greatly reduced since TRD because releases from Trinity Dam have always been less than 14,500 cfs.

Pre-TRD winter baseflows ranged from 3,000 cfs during Wet and Extremely Wet water years, to less than 500 cfs during Critically Dry water years. Winter baseflows were typically established by the first major storm in October or November. Post-TRD winter baseflows have been much lower, ranging from 150 cfs prior to WY1979 to

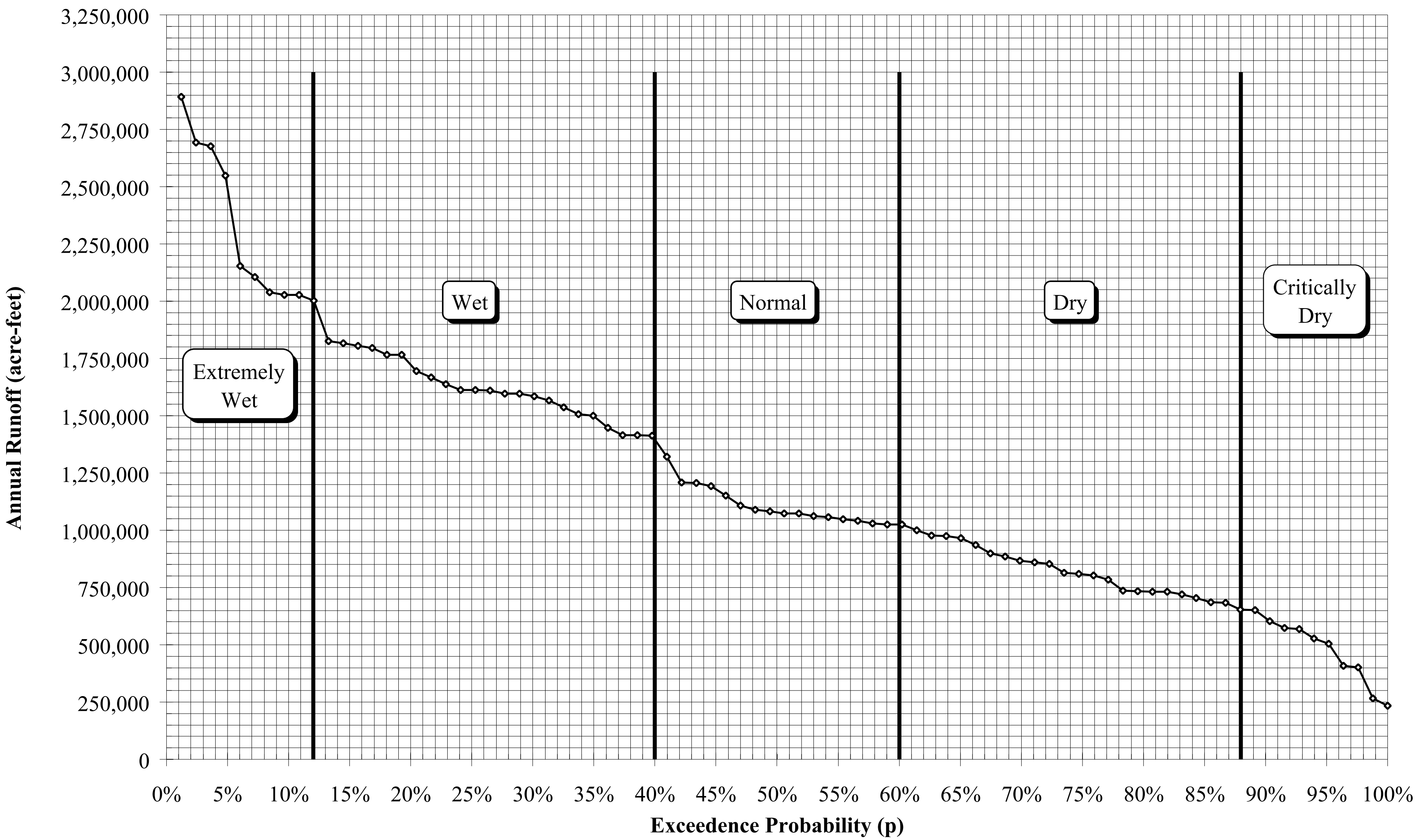


Figure 5.26. Cumulative plot of ranked annual water yields from the Trinity River upstream of Lewiston for 1912-1995.

300 cfs since WY1979. During Wet and Extremely Wet years, extended dam safety releases sometimes function as winter baseflows.

> Trinity River streamflows varied widely, with unimpaired flood events periodically exceeding 70,000 cfs and summer streamflows as low as 100 cfs.

Magnitude of snowmelt peak runoff also is correlated with water-year classification. Extremely Wet water years produced snowmelt peak runoff as great as 26,000 cfs, while Critically Dry water years produced less that 2,000 cfs. Timing of snowmelt peak runoff ranged from late March to late May and generally peaked later in wetter years (Figure 5.27). Duration ranged from a few weeks (WY1976) to 1.5 months (WY1974). This hydrograph component has been all but eliminated by TRD, with the exception of a few experimental or dam safety releases.

Once most of the winter snowpack has melted, the annual hydrograph steadily decreases with occasional brief spikes. This snowmelt recession typically ends by late May during Critically Dry water years, but can extend into late July during Extremely Wet water years. The descending limb has a steep early segment and is followed by a less-steep recession limb. The descending limb receded at an average rate of 650 cfs/day. The recession limb typically begins at flows less than 4,500 cfs and recedes at an average rate of 100 cfs/day, spanning approximately 24 days.

Pre-TRD summer baseflows typically ranged from 100 cfs during Critically Dry water years to about 300 cfs during Wet and Extremely Wet water years (Figure 5.28). During Critically Dry water years, summer baseflows could be as low as 25 cfs. Post-TRD summer baseflows ranged from 150 to 200 cfs prior to WY1979, were held to 300 cfs from WY1979 to WY1990, and have been 450 cfs from WY1991 to present.

Tributary accretion below Lewiston has hydrologic and geomorphological significance. Four major tributaries join the Trinity River within the short mainstem segment from Indian Creek to Browns Creek. Tributary-derived floods exceed dam-release floods downstream from the Indian Creek confluence (RM 95.3). This hydrological transition area coincides with an alluvial transition zone (Trush et al., 1995) where tributary flow and sediment contributions begin to restore alluvial attributes. Downstream tributaries cannot replace lost snowmelt and recession hydrograph components originating upstream from Lewiston, but they do contribute significant winter and summer baseflow. The magnitude of releases from Lewiston Dam can triple (or more) within 30 miles downstream due to tributary accretion.

5.4.2 Channelbed Hydraulics

Channelbed particle size ranges from sand to boulder. Complex flow hydraulics caused by channel meandering and geologic controls sort these particles into a variety of fluvial features such as riffles (cobbles) and pools (gravels and sands). Healthy alluvial ecosystems require frequent mobilization of the channelbed and alternate bars to facilitate bedload transport and routing, to discourage riparian vegetation from colonizing and fossilizing alluvial features, to periodically cleanse fine-grained particles from spawning gravel deposits, and to otherwise rejuvenate a wide range of alluvial features (Section 4.8, Attribute No. 3).

5.4.2.1 Channelbed Mobility

Channelbed mobility was monitored at all WY1991 and WY1992 monitoring sites (Table 5.4). These sites, with established riparian berms, represent post-TRD channel morphology. Channelbed mobility was monitored at 3 bank-rehabilitation sites: Steiner Flat (RM 91.8), Bucktail

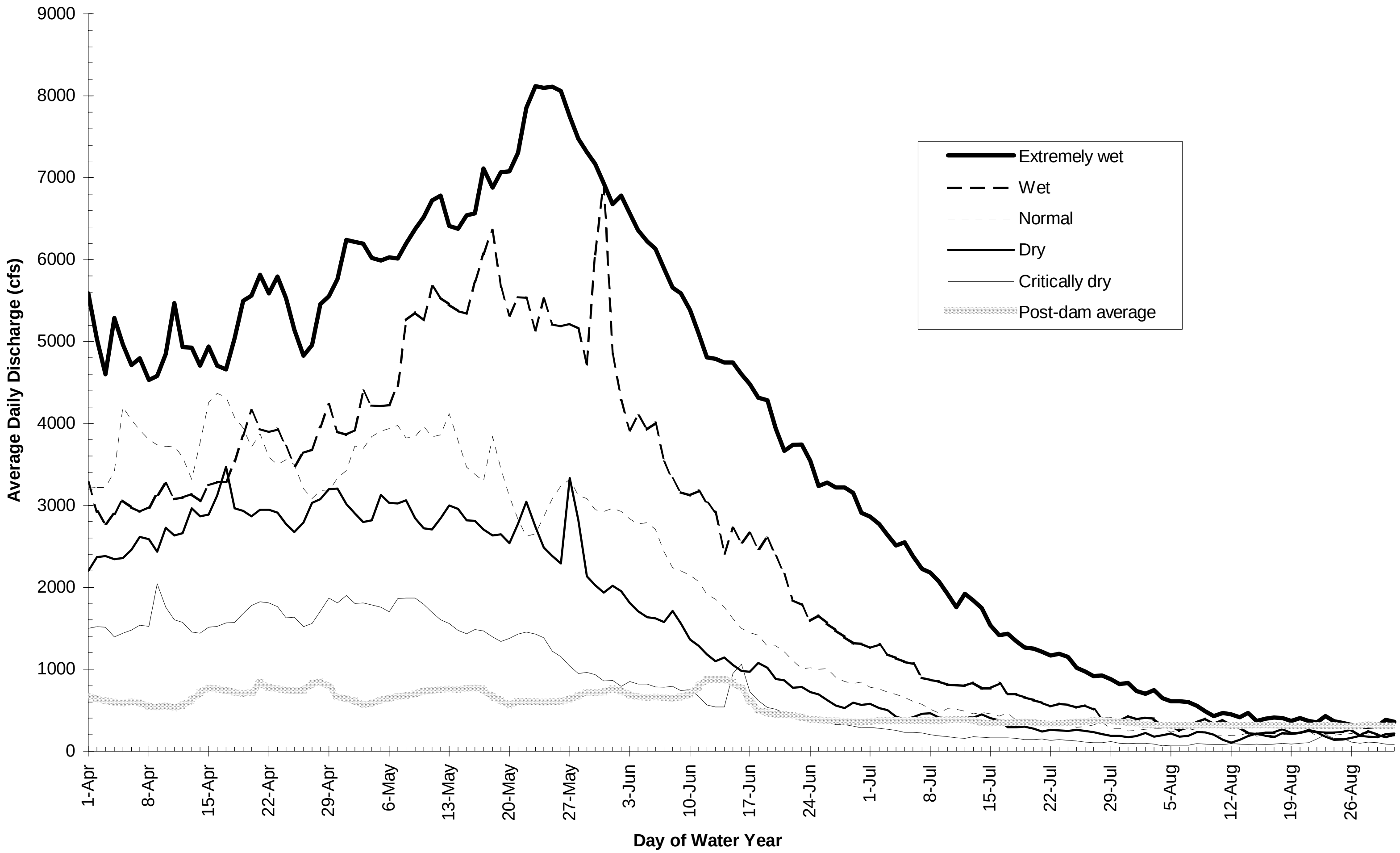


Figure 5.27. Average annual hydrographs of five water-year classes during snowmelt runoff period for all water years at the USGS gaging station at Lewiston (RM 110.9).

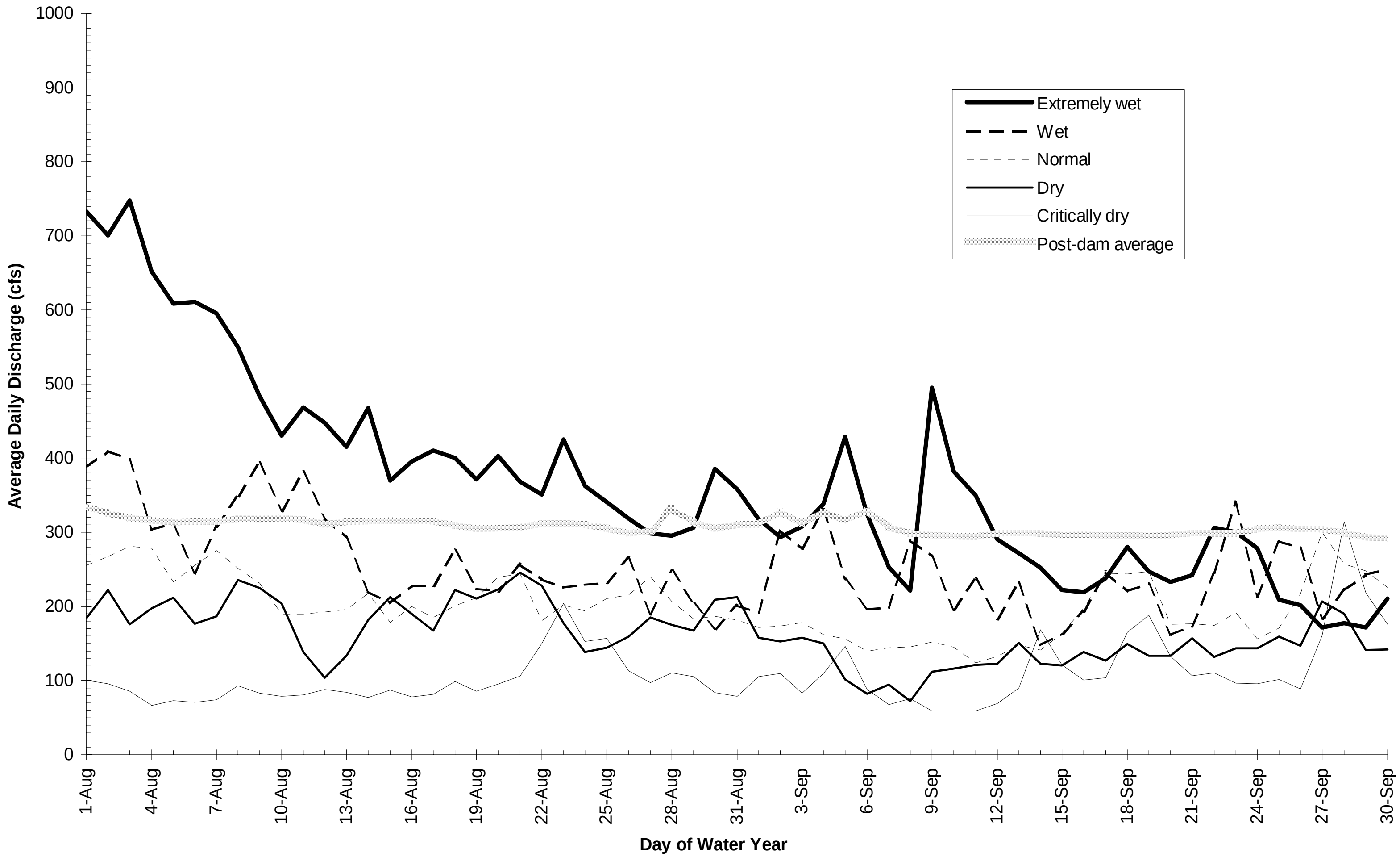


Figure 5.28. Average annual hydrographs of five water-year classes during summer baseflow period (August and September), for all water years at the USGS gaging station at Lewiston (RM 110.9).

Table 5.4. D_{50} and D_{84} tracer gravel mobility comparison between 2,700 cfs release (1991) and 6,500 cfs release (1992) at five consistent monitoring sites and cross section stations.

Gravel Plant Study Site RM 105.5

	Percentage of Particles Mobilized	
Cross Section/Particle Size	2,700 cfs (1991)	6,500 cfs (1992)
10+00/D50	28	80
10+00/D84	8	96

Steel Bridge Study Site RM 99.2

	Percentage of Particles Mobilized	
Cross Section/Particle Size	2,700 cfs (1991)	6,500 cfs (1992)
11+75/D50	20	94
11+75/D84	20	100
10+41/D50	43	100
10+41/D84	25	94
07+18/D50	30	100
07+18/D84	34	100

Indian Creek Study Site RM 95.2

	Percentage of Particles Mobilized	
Cross Section/Particle Size	2,700 cfs (1991)	6,500 cfs (1992)
11+55/D50	100	100
11+55/D84	97	100
10+00/D50	98	100
10+00/D84	82	100

Steiner Flat Study Site RM 91.7

	Percentage of Particles Mobilized	
Cross Section/Particle Size	2,700 cfs (1991)	6,500 cfs (1992)
10+56/D50	100	100
10+56/D84	97	100
00+45/D50	84	100
00+45/D84	76	93

Upper Sky Ranch Study Site RM 81.6

	Percentage of Particles Mobilized	
Cross Section/Particle Size	2,700 cfs (1991)	6,500 cfs (1992)
10+00/D50	75	100
10+00/D84	55	80

(RM 105.6), and Sheridan Creek (RM 82.0) during WY1996 and WY1997. These sites represent what channelbed hydraulics might be like (anticipated future channel morphology) in a rehabilitated channel. Detailed site descriptions and methods are provided in Trinity Restoration Associates (1993) and McBain and Trush (1997).

> Periodic mobilization of gravel deposits creates and maintains high quality salmonid spawning and rearing habitat, and discourages riparian encroachment on gravel bars. Gravels and cobbles in undisturbed low-gradient alluvial rivers are typically mobilized every one to two years.

Incipient mobility studies had two objectives: (1) providing data to calibrate an incipient bed mobility model for the Trinity River mainstem; and (2) using the model to forecast flow magnitudes necessary to induce incipient mobility at other locations with other hydraulic characteristics, e.g., the upper channelbed surfaces of alternating bars (Trush et al., 1995; McBain and Trush, 1997). Cross sections were established at each study site. Particle-size distributions (represented by D_{16}, D_{31}, D_{50}, D_{69}, and D_{84}, the size particle whose diameter is larger than the subscripted percentile of all particles in the distribution) were determined for each cross section using pebble counts. Three size classes of tracer rocks were placed along each cross section to document channelbed mobility at quantified peak discharges: D_{84} tracers on the cross section, D_{50} tracers 2 feet upstream, and D_{16} tracers 3 feet upstream. Occasionally, D_{31} and D_{69} tracers were placed with the other tracers. Tracers were painted bright colors and numbered, then placed into the channelbed by removing a natural rock of similar size and placing the tracer rock in its location. Locations of the tracer rocks were precisely surveyed. After high-flow releases, the tracers rocks were resurveyed to measure movement.

> Streamflows in the 5,000 cfs to 6,000 cfs range begin to mobilize larger cobbles and gravels on newly formed gravel bars.

Trinity Restoration Associates (1993) documented bed mobility for a 2,700-cfs release in WY1991 and a 6,500-cfs release in WY1992. The 2,700-cfs release mobilized finer grained particles and coarser particles on the steepest flanks of alternate bars. This flow also mobilized sand and gravel deposits overlying coarser channelbed surfaces in pool tails. The D_{50} rocks were mobilized on straight reaches and along the low-water margins of point bars. The 6,500-cfs release mobilized most particle sizes in straight reaches and larger particle sizes on the alternate bar surfaces. Rocks up to D_{84} were mobilized at these higher flows, although bar morphology remained relatively unchanged after both releases.

Mobility of tracer rocks on newly formed point bars at the Bucktail and Steiner Flat bank-rehabilitation sites was studied during flows of 5,400 cfs (WY1996), and at all 3 sites during WY1997 floods. The 5,400-cfs flow just began to mobilize D_{84} rocks near the lower bar surfaces (at approximately the 450-cfs water surface where riparian initiation is common (Figures 5.29 to 5.32)). Smaller rocks were mobilized over larger areas of the bars. These results indicate that 5,400-cfs flows begin to mobilize lower alternate bar surfaces and straight reaches, but higher flows are needed to mobilize entire bar surfaces. The WY1997 floods caused significant surface mobilization across the entire bars at all three bank-rehabilitation sites. WY1997 peak flows at the Bucktail, Steiner Flat, and Sheridan Creek sites were 11,400 cfs, 24,000 cfs, and 30,000 cfs, respectively.

5.4.2.2 <u>Channelbed Scour and Fill</u>

Channelbed scour was documented by Trinity Restoration Associates (1993) using scour chains installed in a variety of alluvial deposits in 1991 and 1992, and later by Wilcock et al. (1995) and McBain and Trush (1997) in the

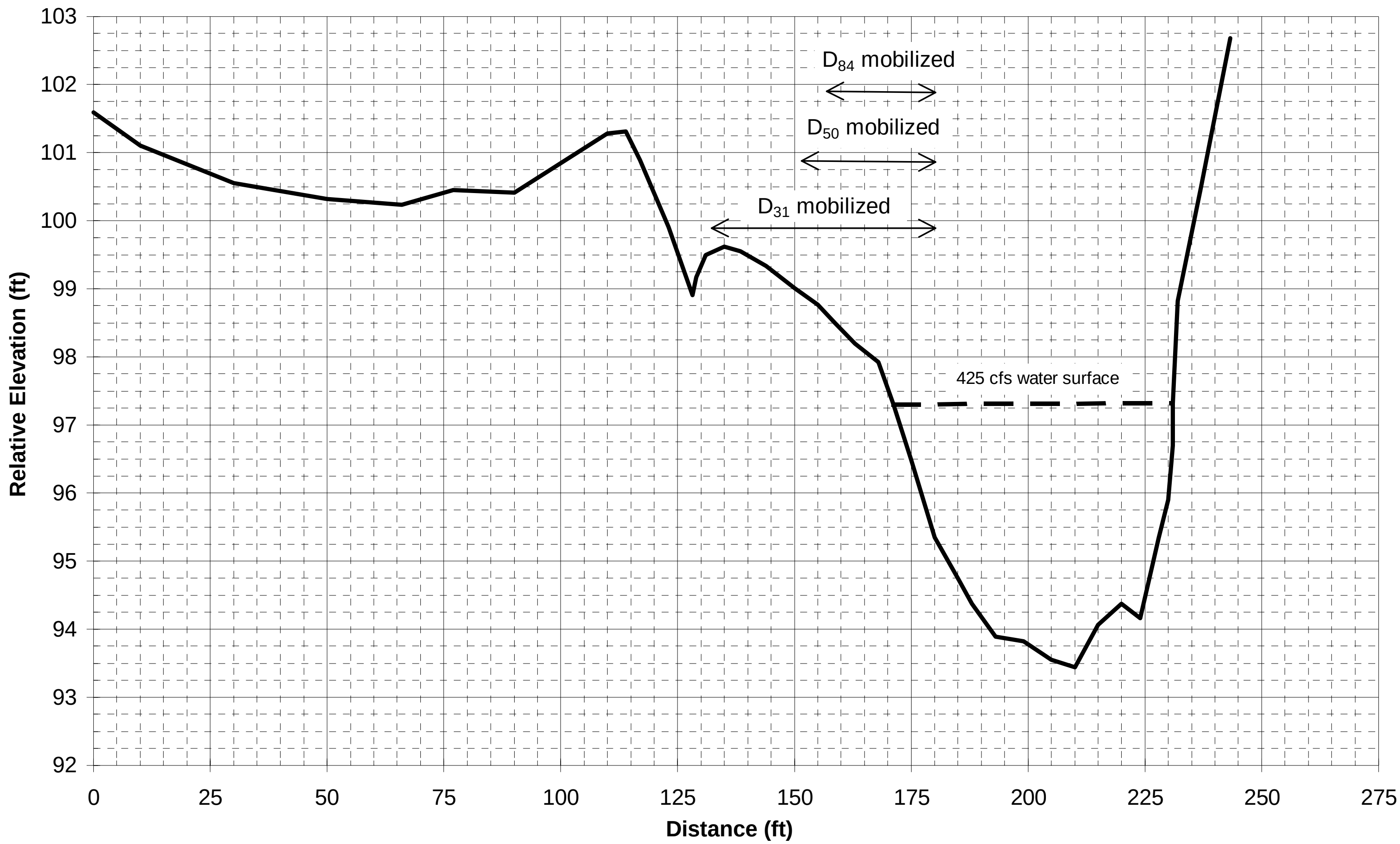


Figure 5.29. Bed mobility pattern at Bucktail bank-rehabilitation site (RM 105.6), cross section 11+00 during 5,400 cfs release. Rocks placed from station 131-179.

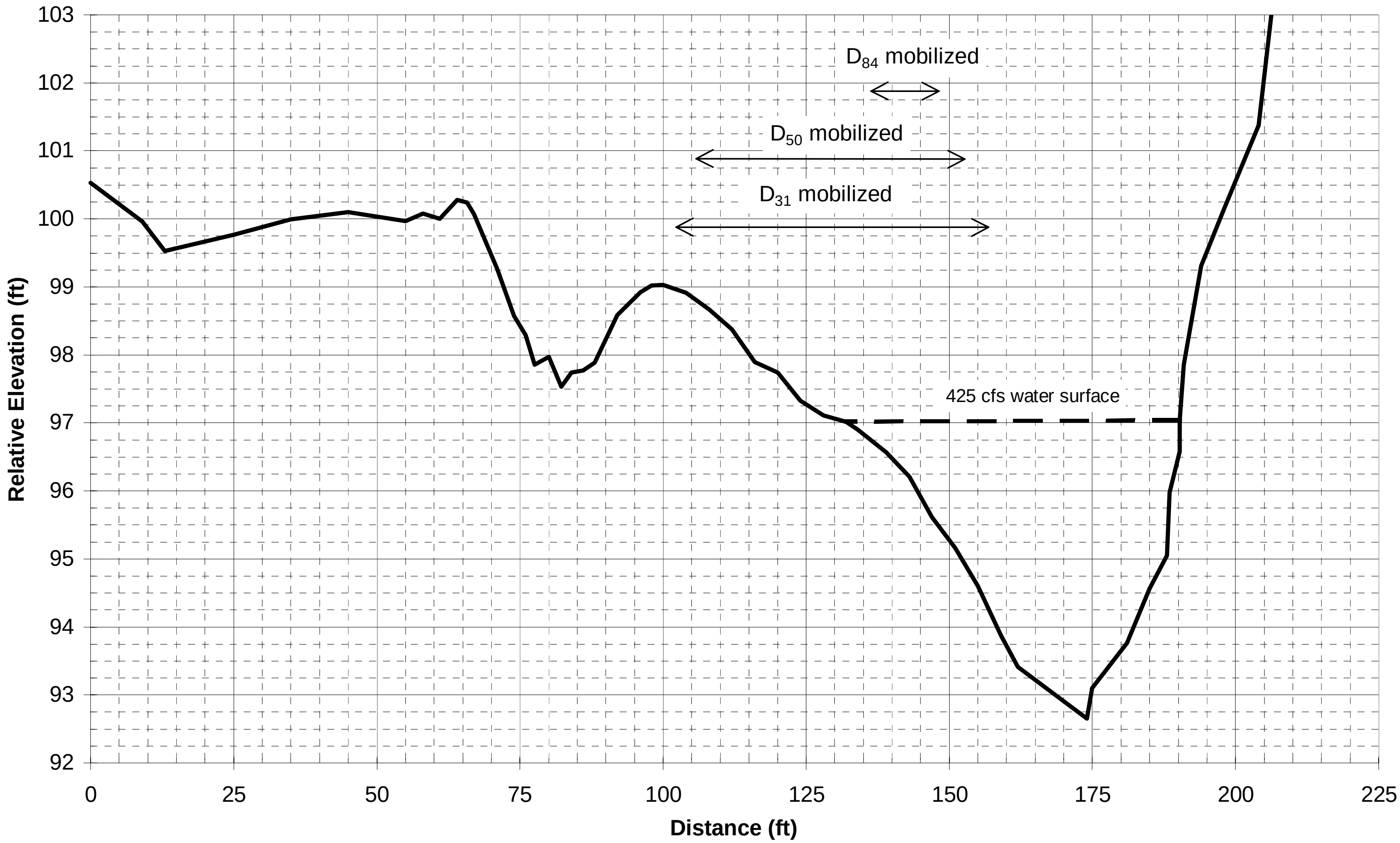


Figure 5.30. Bed mobility pattern at Bucktail bank-rehabilitation site (RM 105.6), cross section 12+00 during 5,400 cfs release. Rocks placed from station 96-156.

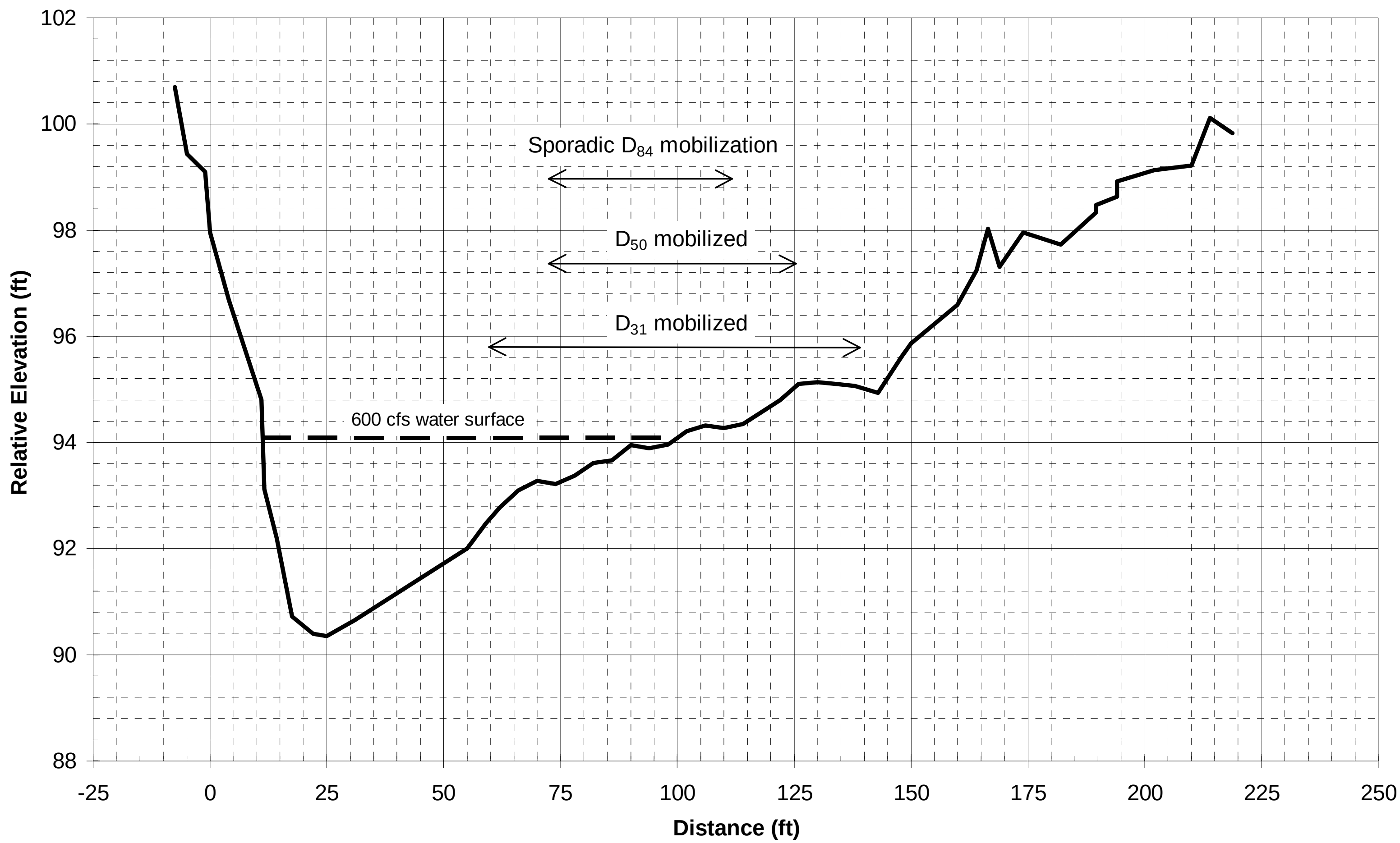


Figure 5.31. Bed mobility pattern at Steiner Flat bank-rehabilitation site (RM 91.8), cross section 5+02 during 5,400 cfs release. Rocks placed from station 62-138.

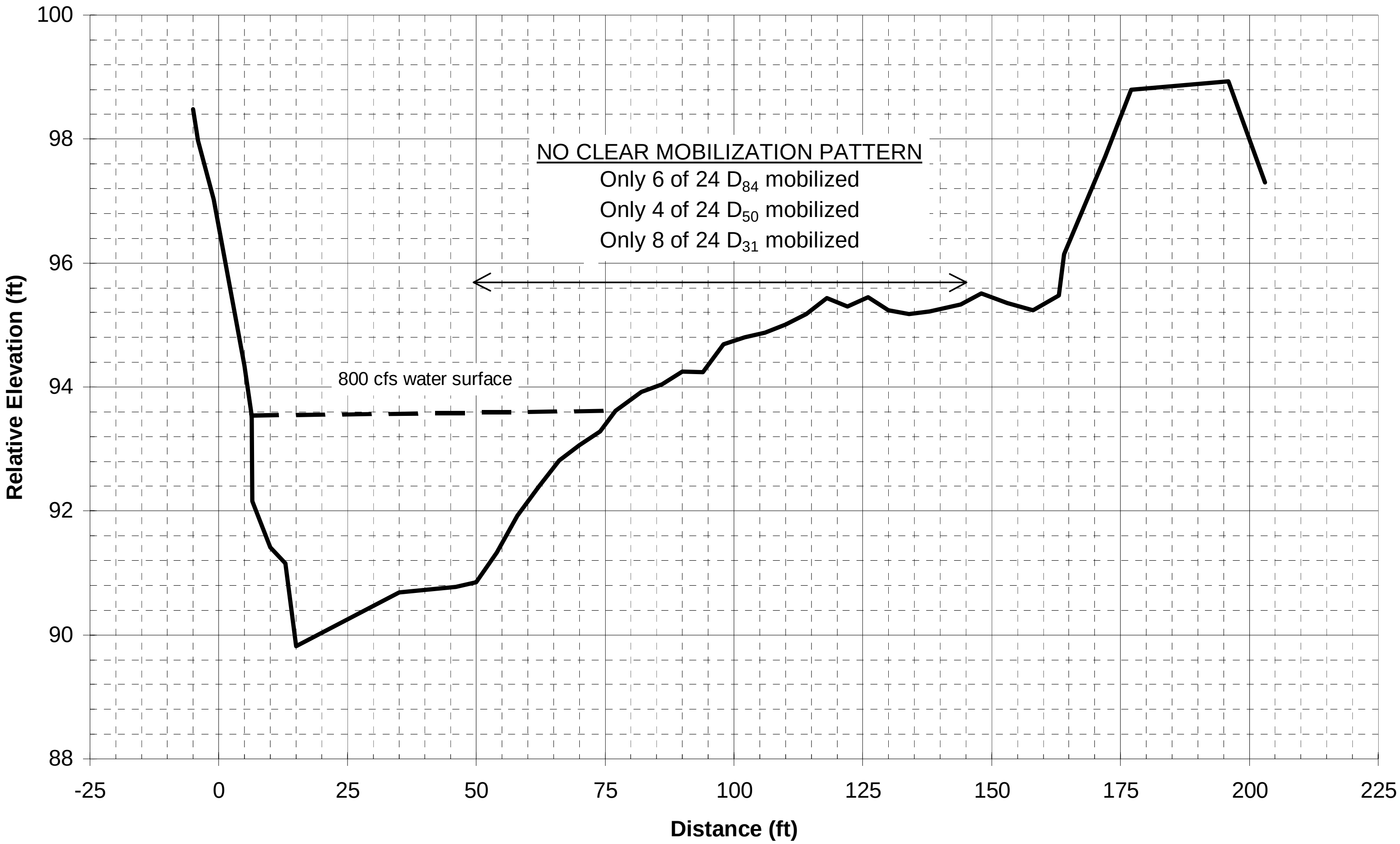


Figure 5.32. Bed mobility pattern at Steiner Flat bank-rehabilitation site (RM 91.8), cross section 5+98 during 5,400 cfs release. Rocks placed from station 52-144.

bank rehabilitation sites. These studies show that a 2,700-cfs flow did not cause significant scour, but scour from a 6,000-cfs flow began to exceed the 2 D_{84} depth in the straight-channel reaches. Significant scour did not occur along the alternate bar flanks, however.

McBain and Trush (1997) installed scour cores (Figure 5.33) on developing point bars at the Bucktail, Steiner Flat, and Sheridan Creek bank-rehabilitation sites (WY1996 and WY1997). Scour cores were placed on the face of point bars between the 300-cfs water surface elevation and the top of the bar. Peak flow releases during WY1996 ranged from 5,180 cfs (Bucktail, RM 105.6) to 5,600 cfs (Sheridan Creek, RM 82.0), indicating minor flow accretion. Scour depths, less than one D_{84} thickness, were approximately the same as subsequent redeposition during the receding limb of the same peak flow. There was no net change in cross section. The WY1997 peak flows ranged from 11,400 cfs at Bucktail to 30,000 cfs at Sheridan Creek, indicating a nearly three-fold flow increase owing to tributary accretion. All scour cores were scoured greater than 2 D_{84} except the highest core at the Bucktail site. A linear plot of discharge versus relative scour depth (Figure 5.34) showed that discharges between 8,000 and 12,000 cfs were necessary to scour greater than 2 D_{84} deep.

Modeling bed scour was attempted, but the difficulty in predicting local shear stress during peak flows precluded results comparable to tracer rock and scour core data results. Developing a better understanding of bed-scour mechanics and increasing the precision of bed-scour predictions should be addressed using an adaptive environmental assessment and management approach.

> Streamflows exceeding 6,000 cfs begin to scour the channelbed surface, while streamflows between 8,000 cfs and 12,000 cfs begin to scour and redeposit gravel bars greater than two particle sizes deep.

> Coarse sediment supplied to the Trinity River by tributaries create the structure of high quality salmonid habitat. Achieving a balancing between coarse sediment supplied to the mainstem Trinity River with gravel transport during TRD streamflow releases ensures that gravel deposits and salmonid habitat are maintained from year-to-year.

5.4.3 Bedload Budgets

Alluvial channel morphology is maintained in dynamic quasi-equilibrium where sediment is exported from the channel reach at a rate roughly equal to the sediment supplied. Coarse and fine sediment are transported through the reach or stored within the channel (dynamic), whereas the channel morphology fluctuates over a narrow range over time (quasi-equilibrium). The sediment budget,

$$I - O = \Delta S \qquad \text{(Equation 5.1)}$$

states that difference between the mass (or volume) of sediment moving into the reach (I), and the mass of sediment leaving the reach (O) is the change in sediment storage in the reach (ΔS) for channels in dynamic quasi-equilibrium (i.e., $\Delta S = 0$). In the post-TRD mainstem, sediment input from the watershed upstream from Lewiston Dam has been eliminated (I=0). Sediment output has been greatly reduced, but not eliminated, by flow regulation. In order to satisfy Equation 5.1, sediment storage in the reach below Lewiston Dam has decreased ($\Delta S < 0$). Therefore, this reach is not in dynamic quasi-equilibrium. Alluvial channels not in dynamic quasi-equilibrium tend to undergo changes in channel morphology (Williams and Wolman, 1984; Kondolf and Matthews, 1993).

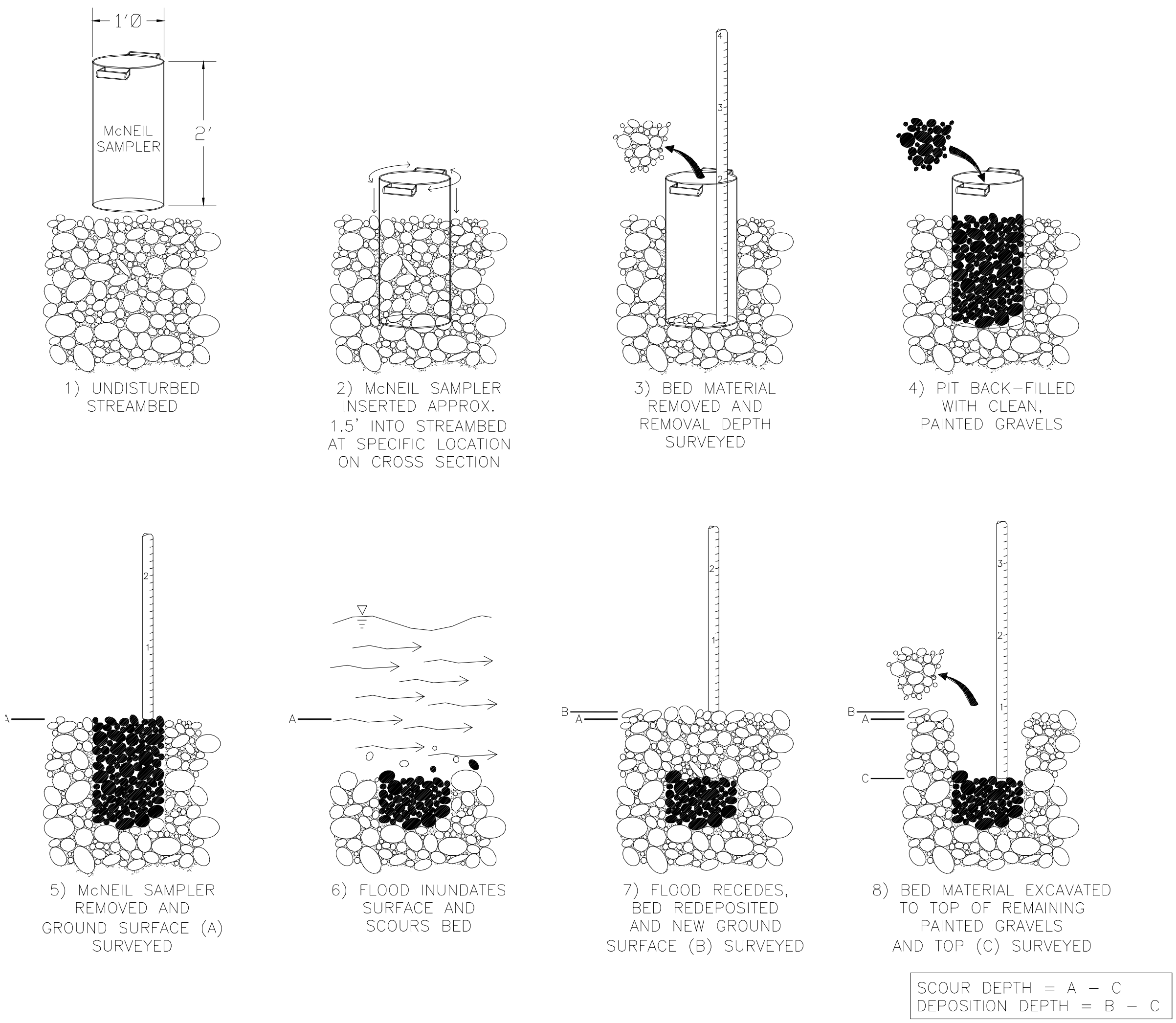


Figure 5.33. Methods for installing scour rock cores, and formulas for computing scour and deposition depth.

In cases where coarse sediment is in deficit, such as downstream from Lewiston Dam, desirable instream alluvial features such as alternate bars and spawning gravel deposits are gradually lost during periods of sediment transport. Most remaining mainstem coarse sediment stored in the reach below Lewiston has either been fossilized by riparian encroachment, abandoned in non-active parts of the former floodplain, or paved. Tributaries now provide the only significant coarse sediment supply.

Fine sediment supply to the mainstem has increased as a result of intensive land use in many tributary watersheds (BLM, 1995). Grass Valley Creek has the dubious distinction as the primary source of fine sediment oversupply to the Trinity River mainstem. The impact of increased fine sediment supply from tributaries is amplified by reduced transport capacity of the mainstem owing to decreased flows imposed by TRD. The increased fine sediment supply in combination with decreased carrying capacity, has allowed fine sediment to accumulate in pools and on riparian berms and to infiltrate gravel deposits.

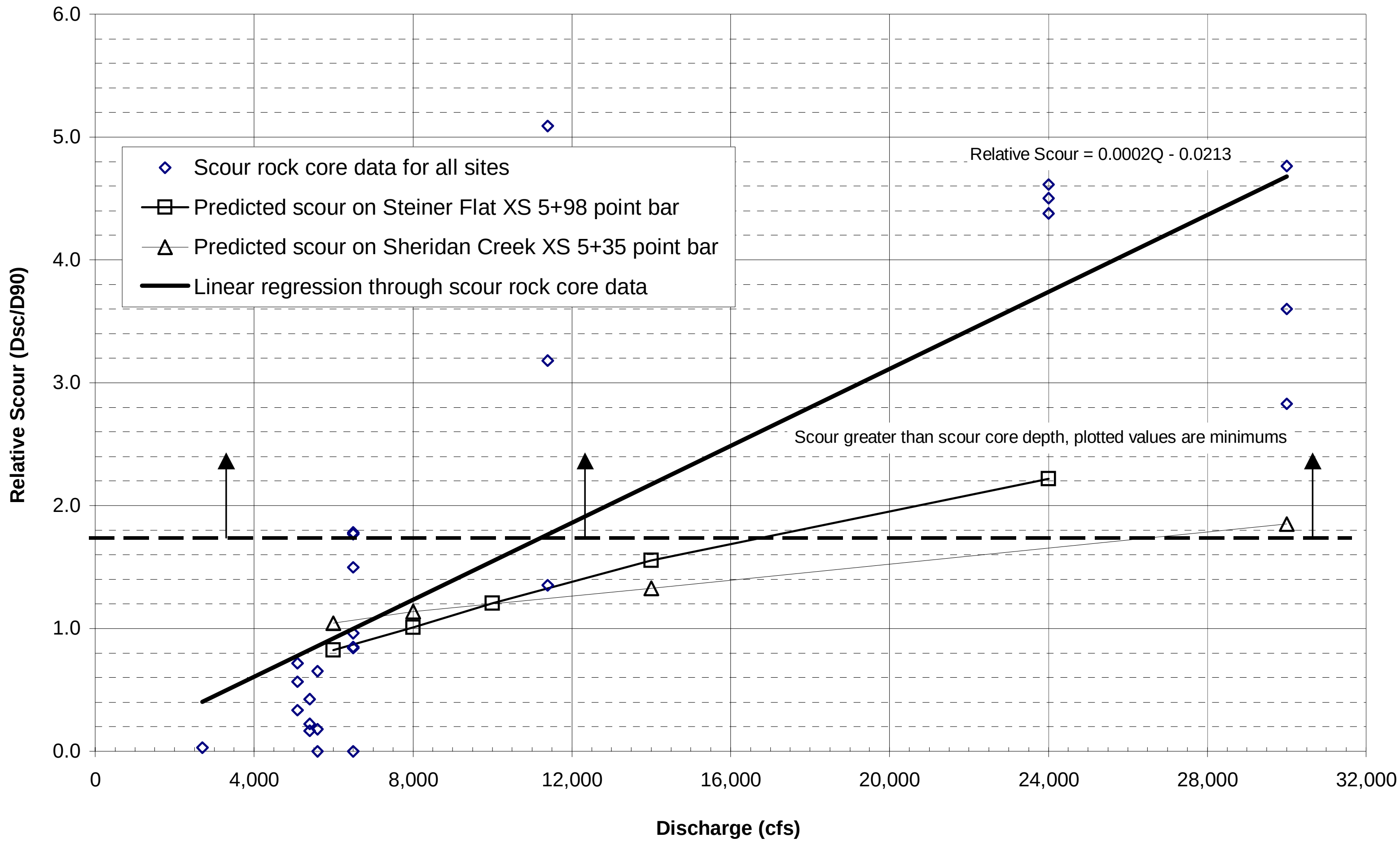


Figure 5.34. Relative scour depth (D_{sc}/D_{90}) as a function of discharge on newly formed point bars at bank-rehabilitation sites, including Wilcock et al., (1995) data.

Objectives for the studies described in this section were to (1) identify Trinity River mainstem reaches where coarse bed material supply is less than current and future transport capacities; (2) predict flows necessary to distribute tributary-supplied coarse bed material; (3) identify candidate reaches where coarse bed material should be augmented to balance the coarse sediment budget; and (4) predict volumes of coarse bed material needed to be introduced in these candidate reaches. Coarse bed material was quantified as that portion of the bedload transport greater than $^{5}/_{16}$ inch (Figure 5.35). This size delineation was chosen for data continuity with other researcher's work (Wilcock et al., 1995); it is a size class that is virtually never transported in suspension, which eases modeling assumptions, and is not harmful to salmonid habitat.

5.4.3.1 Coarse Bed Material Sampling Methods

The Trinity River reach from Lewiston Dam (RM 111.9) to the Weaver Creek confluence (RM 93.8) has been most affected by inadequate coarse sediment supply and oversupply of fine sediment (Ritter, 1968). For these reasons, this reach was selected for detailed study. The reach was divided into five subreaches where coarse sediment budget computations (Equation 5.1) could be made to describe specific balances or imbalances (Figure 5.35). A combination of historical and new sediment sampling stations were used: Deadwood Creek (RM 110.8), Rush Creek (RM 107.5), Grass Valley Creek (RM 104.0), Indian Creek (RM 95.3), Lewiston Cableway (RM 110.2), and Trinity River near Limekiln Gulch (RM 98.3). The USGS has measured bedload and suspended sediment transport at the Grass Valley Creek near Fawn Lodge gaging station (11-525600) from 1975 to 1997, and at the Trinity River near Limekiln Gulch gaging station (11-525655) from 1981 to 1991. The USGS sampling effort was supplemented in 1997 with the other tributary and mainstem stations, topographic monitoring of tributary deltas, and topographic monitoring of the Hamilton Ponds at the mouth of Grass Valley Creek.

Bedload transport was estimated at tributary and mainstem stations using either a hand-held 3-inch or cable-deployed 6-inch Helley-Smith pressure-difference samplers (Helley and Smith, 1971). Suspended sediment was sampled using depth-integrating samplers and USGS protocols (Guy and Norman, 1970; Edwards and Glysson, 1988). Refer to McBain and Trush (1997) for specifics on deployment, sample time intervals, and grain-size analyses. USGS bedload and suspended-sediment transport data were used for computing sediment transport rates in Grass Valley Creek and Trinity River near Limekiln Gulch. After lab analysis of the sediment samples, rating curves for bedload and suspended-sediment transport rates (tons/day) were computed using standard procedures (Edwards and Glysson, 1988). Separate bedload rating curves were developed for sediment coarser and finer than $^{5}/_{16}$ inch.

Significant coarse bedload transport occurs at flows that cannot readily be sampled owing to excessive flow velocities and debris. Because of

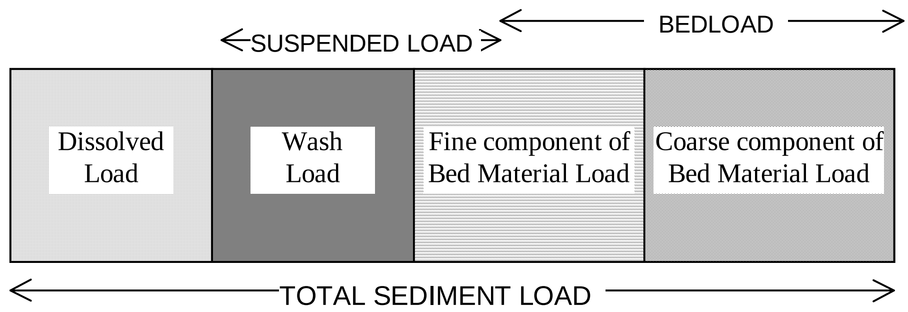


Figure 5.35. Delineation of total sediment load generated from a watershed. The coarse component of bed material load is typically beneficial to salmonid habitat (e.g., spawning gravel, point bars), while the fine component of bed material load is typically harmful to salmonid habitat (e.g., clogging of spawning gravels, embeddedness). Proportions of total sediment load in each box is unique to each watershed.

this, bedload sediment transport rating curves had to be extended. To improve extrapolation of the transport data to higher flows, bedload transport rating curves were fit to equations of the form (Wilcock et al., 1995):

$$Q_b = (w/a)*(Q-Q_c)^b \text{ (Equation 5.2)}$$

where:

Q_b is bedload transport (tons/day), either > $^5/_{16}$ or < $^5/_{16}$ inch,

w is the width of the active bed (feet) during transport,

a is a fitted coefficient (typically in the range of $1x10^5$ to $1x10^8$),

Q is the flow (cfs),

Q_c is the flow at which no bedload transport occurs, and

b is a fitted parameter typically between 2 and 3.

This rating curve form was used to estimate bedload transport at Deadwood Creek, Rush Creek, Indian Creek, Trinity River at Lewiston, and Trinity River near Limekiln Gulch sediment-measurement stations. Published USGS data were used for estimating bedload transport from Grass Valley Creek.

Topographic surveys of the Hamilton Ponds (on Grass Valley Creek 0.5 mile upstream from the Trinity River confluence; designed to reduce sediment entering the Trinity River from Grass Valley Creek) were used to obtain an independent estimate of coarse sediment transport in the Grass Valley Creek watershed. These ponds are periodically dredged to remove sediment that accumulated the previous winter. Repeat topographic surveys by NRCS (Roberts, 1996) and McBain and Trush (1997) provided coarse sediment deposition volume for discrete storm events as well as integrating sediment deposition over each water year.

Topographic surveys also were made on the tributary deltas of Deadwood Creek and Rush Creek. Tributary delta topography was surveyed from the tributary confluence downstream on the mainstem immediately before and after tributary flood events. When tributaries were flooding, mainstem releases often remained near 300 cfs, allowing tributary-derived coarse bed material to accumulate as deltas. These surveys allowed limited calibration to rating curve extensions (i.e., prediction of transport using flow and bedload rating curves should match delta accumulation).

5.4.3.2 Coarse Bed Material Sampling Results

Three mainstem bedload-transport measurements were made at the USGS cableway at Lewiston during the high-flow releases following the January 1, 1997 flood (Figure 5.36). Data collected suggest an estimated 25,000 tons of coarse bed material and 2,500 tons of fine bed material were transported past the site during WY1997. Deadwood Creek is the only tributary upstream from the Lewiston sampling station, and because Deadwood Creek does not produce a significant volume of fine bed material load, fine bed material supply and transport at the Lewiston gage sampling station is low. Fine-grained bed material load was no more than 10 percent of the total bed material load in any sample collected.

> The Trinity River from Lewiston Dam to Rush Creek will require yearly supplementation of coarse sediment due to the TRD blocking coarse sediment supply from the upper watershed, otherwise spawning gravels and gravel bars will be gradually depleted.

USGS has collected bedload transport data at its Limekiln Gulch gaging station from 1981 to 1992. As part of this study, two additional bedload transport measurements were made in WY1997. The WY1997 annual hydrograph was reconstructed from selected flow measurements, staff plate observations, and upstream gaging stations. The bedload transport rating curve (Figure 5.37) was used to estimate transport of 20,400 tons of coarse bed material and 12,600 tons of fine bed material past this site in WY1997. These WY1997 estimates closely agreed with the best-fit line for USGS bedload measurements from WY1989 to WY1991. USGS bedload data from WY1981 to WY1986 show much greater bedload transport rates at low flows than at similar flows during the WY1989 to WY1991 period, indicative of decreasing sand supply over time.

Rating curves for Deadwood Creek, Rush Creek, and Indian Creek were prepared using both simple power functions ($Q_s = aQ^b$, where "*a*" is a coefficient and "*b*" is the exponent describing the slope of the best-fit line) and Equation 5.2. Improved data fit was obtained by subdividing into pre- and post-January 1, 1997, flood periods and segregating rising/falling limb data sets to account for storm hysteresis. Predicted coarse tributary bed material yields for WY1997 are given in Table 5.5.

5.4.3.3 WY 1997 Coarse and Fine Bed Material Budget

Using the predicted mainstem Trinity River coarse sediment transport values of 25,000 tons and 20,400 tons at the Lewiston and Limekiln Gulch stations, respectively, a coarse bed material sediment budget was developed for WY1997. Comparing the 25,000 tons transported at Lewiston with the 140 tons contributed from Deadwood Creek and 16,100 tons contributed from Rush Creek indicated that the mainstem Trinity River was in a coarse bed material deficit at least downstream from Rush Creek (16,100 + 140 – 25,000 = 8,760 tons deficit) and possibly farther downstream. Therefore, significant coarse bed material augmentation would be required upstream from Rush Creek to balance the annual coarse bed material budget.

The corresponding fine bed material transport was 2,500 and 12,600 tons at the Lewiston and Limekiln Gulch stations, respectively. The fine bed material budget was in deficit downstream to Rush Creek (-2,460 tons), then in surplus downstream from Rush Creek (+16,100 tons using Lewiston data; +6,000 tons using Limekiln data).

The volume or mass of sediment transported in any given year for any given tributary is unique. Typically, the wetter the water year, the more sediment transported by tributaries. Ideally, predicting the volume of sediment delivered to the mainstem Trinity River by tributaries for each of the five water-year classes would be based on a long period of record for sediment yield. The only nearby tributary with a long-term sediment transport

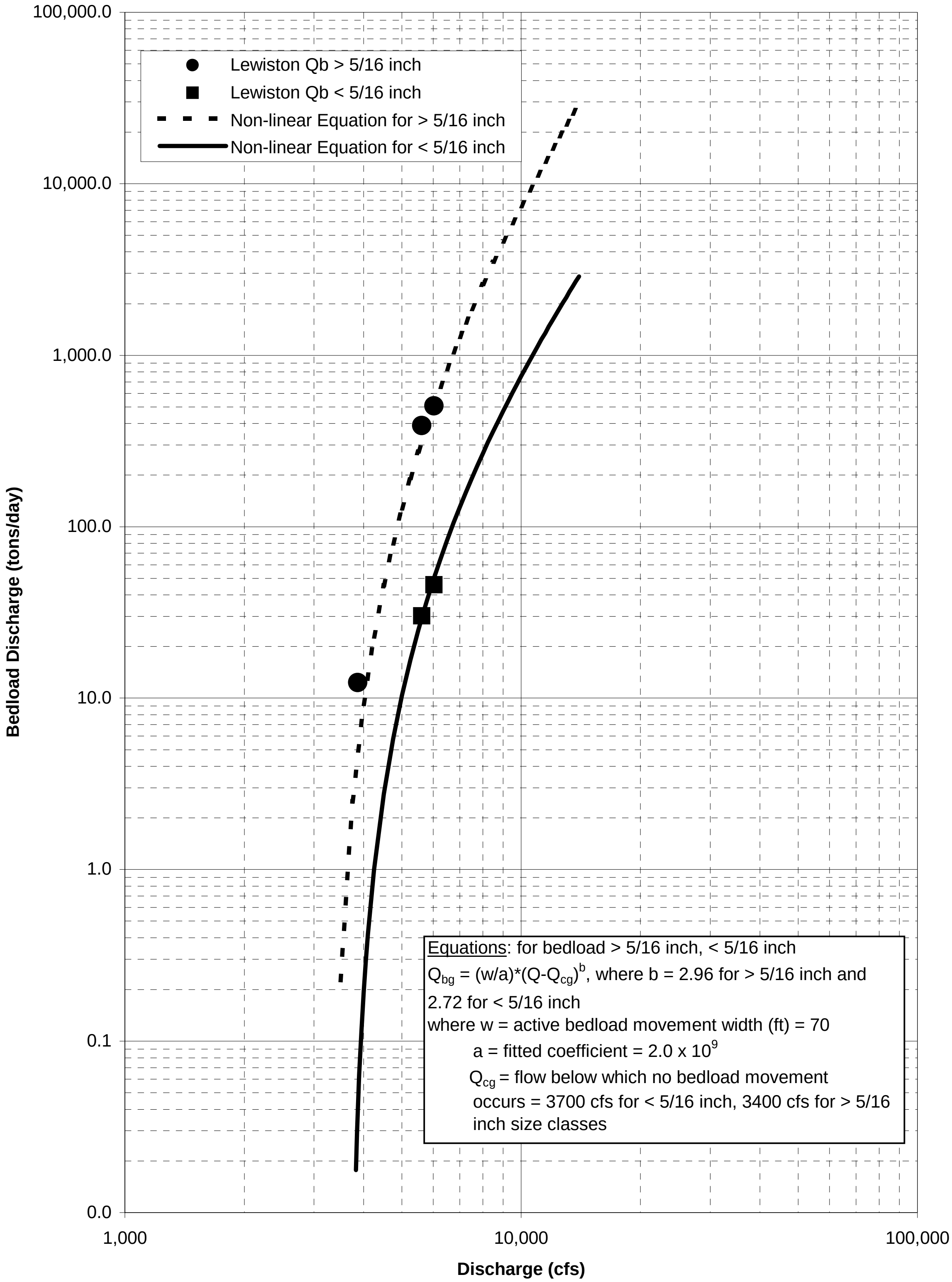


Figure 5.36. Trinity River at Lewiston (RM 110.9) mainstem bedload transport for > $^5/_{16}$ inch and < $^5/_{16}$ inch size classes.

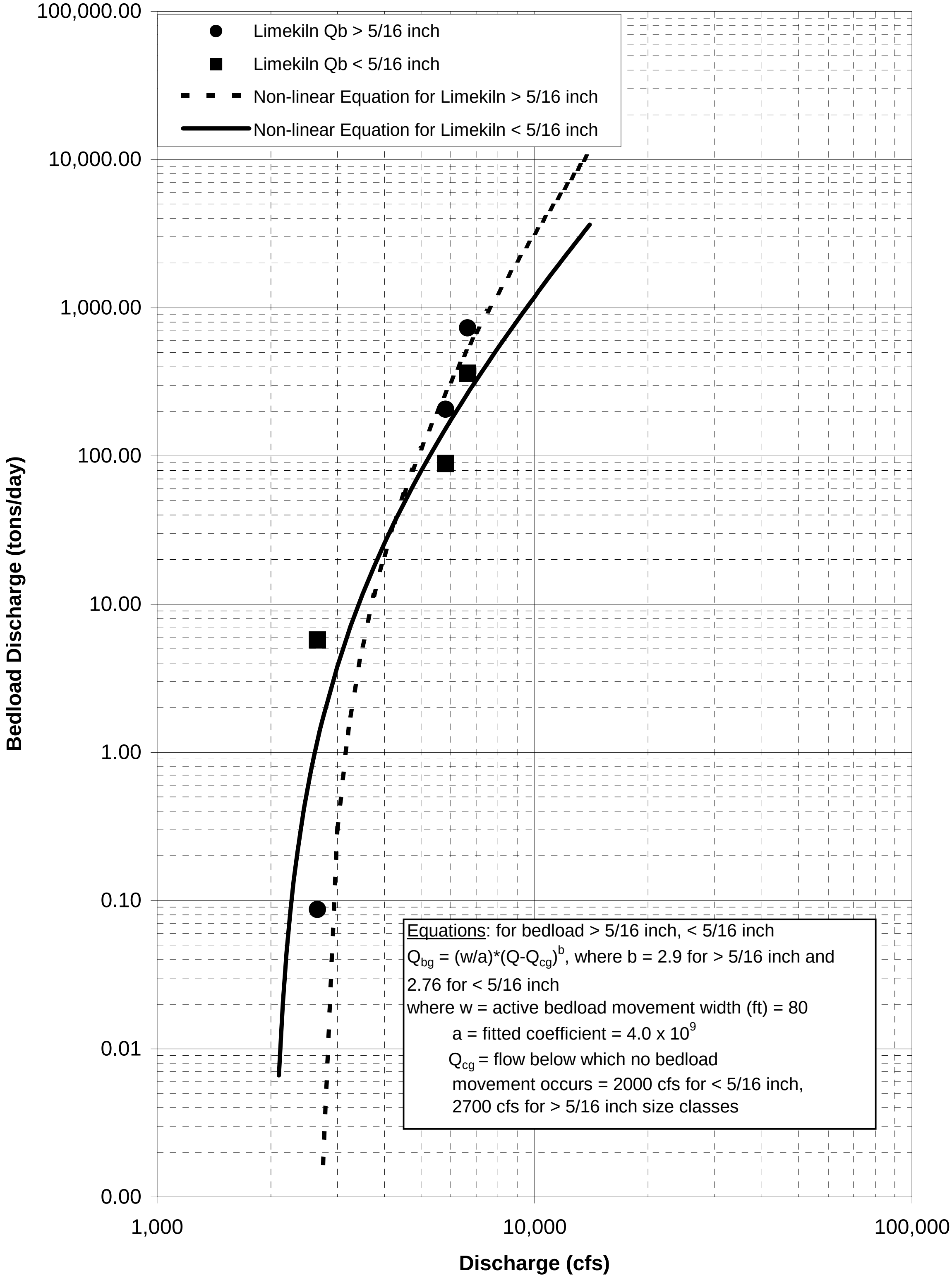


Figure 5.37. Trinity River below Limekiln Gulch (RM 100.9) near Douglas City mainstem bedload transport for > $^5/_{16}$ inch and < $^5/_{16}$ inch size classes.

Table 5.5. Summary of WY 1997 tributary and mainstem bed material load transport.

Station	Total Bedload (tons)	Bedload > $^5/_{16}$ inch (tons)	Bedload < $^5/_{16}$ inch (tons)
Deadwood Creek	180	140	40
Rush Creek	34,700	16,100	18,600
Grass Valley Creek	14,100**	3,700*	>8,900*
Indian Creek	36,500	12,200	24,300
TOTAL:	85,480	32,140	>51,840
Trinity River at Lewiston	27,500	25,000	2,500
Trinity River near Limekiln Gulch	42,600	20,400	12,600
TOTAL:	70,100	45,400	15,100

* based on deposition in Hamilton Ponds (near mouth); portion of fine sediment routed through ponds to mainstem Trinity River.

** based on puiblished USGS data at Grass Valley Creek near Fawn Lodge gaging station, several miles upstream of mouth.

record is Grass Valley Creek. Therefore, Grass Valley Creek was used to extrapolate WY1997 sediment data measured in Deadwood Creek, Rush Creek, and Indian Creek to predict average annual sediment yield for each water-year class (Table 5.6). This prediction was then used to estimate peak flow duration for each water year required to transport that volume or mass of coarse bed material load downstream. For example, if tributaries delivered 10,000 tons of coarse bed material in a Wet water year, the 8,500-cfs peak would have to occur for 3 days for the mainstem to transport 10,000 tons based on the Lewiston bedload rating curve. A secondary objective was to determine whether the introduction of coarse bed material below Lewiston Dam would be needed, and if so, at what rates, for each water-year class.

Long-term annual coarse bed material input for each of the tributaries was predicted by correlating measured tributary coarse bed material yields with peak discharges from Grass Valley Creek. Extrapolating this tributary coarse bed material yield to Grass Valley Creek peak discharge to 1976 provided 21 years of synthetic coarse bed material yield from tributaries. Next, for each tributary, coarse bed material loads were grouped and averaged for each water-year class (Table 5.6).

The TRD is better able to manage mainstem coarse bed material transport nearer Lewiston Dam; therefore, Rush Creek was chosen as the initial point of balancing the coarse bed material budget. Next, a matrix of mainstem coarse bed material transport was developed for the Trinity River at Lewiston and Trinity River near Limekiln Gulch sediment-monitoring stations (Table 5.7). Using peak flow magnitudes determined from bed mobility and

Table 5.6. Estimated coarse bed material yields by water-year classification for major tributaries.

Water Year Classification	Deadwood Creek (tons)	Rush Creek (tons)	Grass Valley Creek at Mouth (tons)	Indian Creek (tons)
EXTREMELY WET average:	280	48,600	12,800	164,000
WET average:	50	9,000	3,050	14,300
NORMAL average:	4	800	1,300	340
DRY average:	2	290	1,150	85
CRITICALLY DRY average:	0	0	700	0

bed scour objectives (11,000 cfs for Extremely Wet years to 2,000 cfs for Critically Dry years), the following estimated flow durations are required to transport the coarse bed material load from Deadwood Creek and Rush Creek:

Extremely Wet — 48,880 tons of supply: 5 days of 11,000 cfs and 5 days of 6,000 cfs transports 53,000 tons using Lewiston coarse bed material load data and 25,000 tons using Limekiln Gulch coarse bed material load data.

Wet — 9,050 tons of supply: 5 days of 8,500 cfs and 5 days of 6,000 cfs transports 19,000 tons using Lewiston coarse bed material load data and 9,800 tons using Limekiln Gulch coarse bed material load data.

Normal — 800 tons of supply: 5 days of 6,000 cfs transports 2,250 tons using Lewiston coarse bed material load data and 1,600 tons using Limekiln Gulch coarse bed material load data.

Dry — 290 tons of supply: 5 days of 4,500 cfs transports 175 tons using Lewiston coarse bed material load data and 275 tons using Limekiln Gulch coarse bed material load data.

Critically Dry — Supply is functionally zero, and peak flow is below the threshold to transport coarse bed material load; therefore transport also is functionally zero.

This extrapolation based on a single year of sediment-transport measurement has considerable uncertainty, and these 5-day peak flow durations have corresponding uncertainty. Future flow releases should not strictly follow the above recommendations; rather, management should be adaptive to the conditions of each given year. For example, one Wet year may result in 10,000 tons of coarse bed material load delivered to the Trinity River downstream from Rush Creek, whereas another Wet water year may only contribute 6,000 tons. Therefore, the duration of peak flow release should be shorter for the latter Wet year. The intent of this evaluation is to estimate average duration needed to transport coarse bed material load — knowing that for any given year, the

Table 5.7. Total mainstem bedload transport (> $^5/_{16}$ in) in tons, at the Trinity River at Lewiston gaging station cableway (RM 110.2) and the Trinity River near Limekiln Gulch gaging station cableway (RM 98.3) as a function of release duration.

Discharge (cfs)	1 day	2 days	3 days	5 days	7 days	10 days
	Lewiston					
14,000[1]	29,000	57,500	86,000	144,000	200,000	287,000
11,000	11,000	21,000	32,000	53,000	75,000	107,000
8,500	3,300	6,600	9,900	16,500	23,000	33,000
6,000	450	900	1,350	2,250	3,150	4,500
4,500	35	70	105	175	250	350
2,000	0	0	0	0	0	0
	Limekiln					
14,000[1]	11,350	22,700	34,000	57,00	79,000	113,000
11,000	4,600	9,300	14,000	23,200	32,500	46,000
8,500	1,650	3,300	4,900	8,200	11,500	16,500
6,000	320	640	960	1,600	2,240	3,200
4,500	55	110	165	275	385	550
2,000	0	0	0	0	0	0

[1] 14,000 cfs was included for consideration in event 11,000 cfs does not provide adequate bed scour.

duration will be set by the adaptive environmental assessment and management program based on the coarse bed material yield for that year.

5.4.3.4 Coarse Bedload Routing

Alluvial and mixed-alluvial rivers must route (transport) coarse bed material downstream to maintain bedload transport continuity. Channel down-cutting ensues after high-flow events if there is not an upstream source of coarse bed material to replace bed material transported downstream. Lewiston and Trinity Dams have completely halted coarse bed material routing from sources upstream. The mainstem immediately below Lewiston Dam has responded with slight down-cutting and significant channelbed coarsening.

Bed material routing is also of concern farther downstream. Annual coarse sediment supply from downstream tributaries continues at rates equal to or slightly higher than before TRD, but lower instream flows reduce mainstem transport capacity. Many tributaries now have created deltas in the mainstem. Bed elevation at these deltas have aggraded as much as 8 feet. At Rush Creek, Grass Valley Creek, and Indian Creek, aggraded deltas have caused major backwaters during mainstem high flows. These backwaters decrease slope in the mainstem, prevent coarse sediment from routing past the tributary junctions, and cause coarse and fine sediment to deposit in these backwaters. Deep pools, such as those near Lewiston that exceed a depth of 20 feet, also may prevent or restrict coarse bed material routing. The purposes of this study were to: (1) determine if coarse bed material is being routed past significantly aggrading deltas and historically deep pools upstream from Weaver Creek (RM 93.8) under the contemporary annual flow regime; and (2) identify a peak flow threshold that would allow coarse bed material to be routed past these deltas and pools.

In WY1996, tracer rocks were placed in the mainstem upstream from the tributary deltas of Grass Valley Creek and Indian Creek following the same methodology applied in Section 5.4.2. Tracer rocks were not installed upstream from the Rush Creek delta because of excessive depths and exposed bedrock on the channelbed (routing was modeled instead). Hydraulic conditions (cross sections, water-surface elevation, and water-surface slope) were surveyed at Rush Creek, Grass Valley Creek, and Indian Creek deltas during a 5,100-cfs release. Tracer rocks placed upstream from Grass Valley Creek and Indian Creek had minimal mobilization. Only 17 percent of the D_{84} tracer rocks placed on the riffle crest of the Grass Valley Creek delta were mobilized. Mobility slightly upstream in the backwater was considerably less. For example, at Indian Creek, tracer rocks were placed on a deposition zone at the upstream end of the backwater, more than 500 feet upstream from the Indian Creek delta. None of the D_{84} and 16 percent of the D_{50} tracer rocks mobilized during the 5,100-cfs release. However, coarse bedload was moving into the cross section as evidenced by captured gravel in bedload traps placed on the cross section and by several tracer rocks that were partly buried by new gravel. This coarse bed material was deposited locally at the head of the backwater reach, causing the deposition zone to continue growing toward the Indian Creek delta. Therefore, coarse bed material is not routing past the Grass Valley Creek and Indian Creek deltas.

To determine whether coarse bed material was being routed through deep pools, movement of tracer rocks was monitored during the 5,100-cfs release. As a simple pilot experiment, 200 tracer rocks (D_{84}) were thrown-in immediately upstream from Sawmill Pool (RM 108.6) and Bucktail Pool (RM 104.6) during the rising limb of a dam release. A similar experiment also was performed in other pools in WY1992 (Trinity Restoration Associates, 1993). At both the Sawmill Pool and Bucktail Pool, no relocated tracer rocks were found downstream from the pools after 9 days at a flow of 5,100 cfs; most tracer rocks remained at or near the insertion point. Those that traveled into the pools were immediately deposited on subtle point bars on the inside bend. Tracer rocks deposited on these adjacent point bars may move to the next downstream riffle–pool sequence during future flows, but the experiment was not repeated in subsequent years.

The reduction in high flow regime by the TRD has allowed riparian vegetation to establish on and fossilize gravel bars that are important for salmonid habitat. This riparian encroachment has also formed a sandy berm within the vegetation. A future high flow regime that discourages riparian colonization of gravel bars and encourages riparian colonization of floodplains will reestablish a more natural and healthy riparian community.

In WY1992, several tracer rock sets were placed at the head of riffles to document routing. At the Steiner Flat site (RM 91.7), three tracer rocks (a D_{84}, a D_{69}, and a D_{50}) were transported through a 20-foot deep pool and onto the downstream median bar by the 6,500-cfs release (Trinity Restoration Associates, 1993). These two simple experiments suggested that 5,000 to 6,000 cfs was not only near the threshold for general bed mobilization, but also near the threshold for transporting coarse bedload through alternate bar sequences.

Channelbed surface mobility was modeled in the backwaters of all three deltas using the model described in Section 5.4.2. The Shields parameter for the local D_{84} was predicted at cross sections in the backwater of the Rush Creek, Grass Valley Creek, and Indian Creek deltas, and evaluated using the incipient Shields parameter observed at Steiner Flat. In all cases, predicted Shields parameters for flows up to 14,000 cfs were well below that needed to cause incipient mobility. The low predicted mobilities were caused by backwater-induced low slopes: Rush Creek = 0.00011, Grass Valley Creek = 0.00063, and Indian Creek = 0.0002. Water-surface slopes in most mainstem reaches ranged from 0.001 to 0.002. By increasing slope, best accomplished by partially excavating the deltas and thus lowering the hydraulic control, shear stress can be increased to restore coarse bed material routing.

5.4.4 Riparian Plant Communities

Woody riparian encroachment was instrumental in changing the mainstem's alluvial nature and consequently degrading salmonid habitat. Several important mortality agents that suppressed encroachment prior to TRD depended on the variable unregulated flow regime: bar inundation and desiccation (Section 4.8, Attribute No. 2); frequent mobilization of the channelbed surface that scours seedlings (Section 4.8, Attribute No. 3); less frequent channelbed scour that kills older seedlings (Section 4.8, Attribute No. 4); periodic channel migration that undercuts saplings and mature trees (Section 4.8, Attribute No. 6); scour of mature trees (Section 4.8, Attributes No. 7 and No. 8); and isolation of mature stands through channel avulsions (Section 4.8, Attributes No. 8 and No. 10).

Linking specific hydrograph components with river-channel dynamics and riparian mortality agents provides a framework for recommending how woody riparian encroachment, including riparian berm formation, can be discouraged in the future, and how natural regeneration on the floodplain surfaces can be encouraged. This linkage has been proposed before. Bradley and Smith (1986) showed that desiccation (killing seedlings high on a point bar) and scour (killing seedlings low on the bar) allowed only occasional cottonwood cohorts to survive. Scott et al. (1993), in relating specific components of the annual hydrograph to riparian life-history dynamics, concluded that aside from the rising limb, all aspects of the hydrograph play a vital role in the germination, establishment, and long-term survival of many riparian species. Returning these mortality agents to riparian vegetation near the post-dam low flow channel will encourage self-sustaining diverse riparian plant communities on geomorphic surfaces higher on the floodway (Section 4.8, Attribute No. 9).

5.4.4.1 Woody Riparian Encroachment Processes

Three key life-history characteristics of woody riparian plants can be used to discourage encroachment: a seed can only germinate on surfaces not underwater; a seedling can establish itself only on moist surfaces where water is readily available; and younger plants are easier to remove by scour than older plants. If an alternate bar is submerged during the period in which seeds are released, seedlings can not initiate on the bar surfaces. If seeds are released near the end of snowmelt recession or during summer baseflow, seedling initiation will be constricted to the moist lower bar surfaces (the exposed capillary zone). Seedlings established on these lower bar surfaces are more susceptible to being removed by scour during subsequent high flows (Section 5.4.4.4). In order to identify when inundation and effective channelbed scour would be most effective in minimizing riparian encroachment, it was necessary to: (1) establish seed viability windows for the dominant woody riparian species; (2) document flows that prevent germination by alternate bar inundation; (3) track surface and subsurface moisture in bars; and (4) quantify the depth of scour needed to remove a specific age class of woody riparian plant.

> Periodically scouring new seedlings on gravel bar surfaces near the low water surface will preserve the high quality salmonid habitat that these gravel bars provide.

Woody riparian life histories were monitored during WY1995 through WY1997 (Figure 4.13). Arroyo willow released seeds during or before the spring snowmelt peaks. Cottonwoods dispersed seeds later, during spring snowmelt recession, and for only a short period. Narrow-leaf and shiny willows released seeds beginning in late spring during the snowmelt recession and extending well into summer baseflow, making these species the most aggressive at encroaching onto exposed bar surfaces. White alder dispersed seeds during October low flows, and the catkins are distributed downstream by winter flows, delivering a fresh supply of alder seeds to newly deposited alluvial features. White alder and Oregon ash are the only woody riparian plant species on the Trinity River with seeds viable more than 2 weeks, typically 2 to 3 years.

5.4.4.2 Preventing Seedling Establishment

Encroachment can be discouraged by inundating bars during the seed-release period. Flows just inundating (0.5-foot deep) the tops of newly formed alternate bars at all pilot bank-rehabilitation sites were either documented in the field (with constructed rating curves) or estimated using the Manning's equation. Discharges inundating the bar tops varied by site and exhibited no longitudinal trend downstream (Table 5.8).

An exposed capillary zone extending a short distance above the water surface provides a narrow, but moist, germination surface. Above this capillary zone, the bar surface becomes increasingly dry and hot as summer progresses. This zone moves down the bar face as the water surface declines during the snowmelt recession and summer baseflows. Seedlings germinating high on the bar risk desiccation if their root systems cannot grow fast enough to stay in the moist zone. Species releasing seeds early in summer (e.g., both cottonwood species) are at greatest risk, even though many riparian species can develop extensive root systems quickly (Segelquist et al., 1993). From mid-June to mid-August, the capillary zone becomes the principal location for woody riparian seeds to successfully germinate.

Seedling initiation was monitored from late spring through summer on cross sections at the bank-rehabilitation sites. Water-surface elevations, daily average discharges, and highest elevations of the moist zone were plotted. Maximum elevation for the capillary zone, 2.5 feet above the low summer water surface, was recorded in a sand deposit at the Steiner Flat site. On gravel and cobble surfaces, capillary zones were

Table 5.8. Discharges required to inundate the tops of developed alternate bars (by 0.5 foot) at the bank-rehabilitation sites.

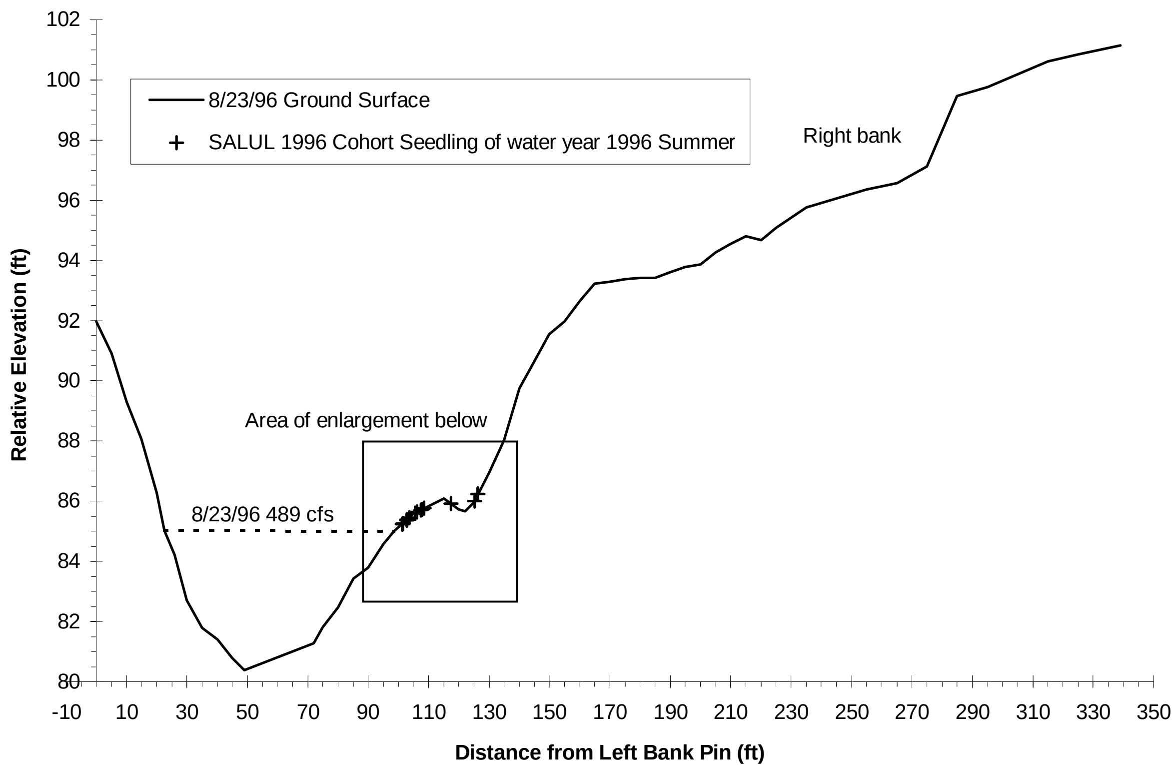
Site (RM)	Cross Section	Discharge to Inundate Bars (cfs)
Bucktail (105.6)	12+00	3,300[2]
Limekiln (100.2)	11+86	no bars
Steel Bridge (98.8)	12+10[1]	450[2]
Steiner Flat (91.8)	05+98	1,300[2]
Bell Gulch (84.0)	11+50	450[2]
Deep Gulch (82.2)	10+00[1]	no bars
Sheridan Creek (82.0)	05+35	1,900[2]
Jim Smith (78.5)	12+10	2,851[3]
Pear Tree (73.1)	15+00	1,300[3]

[1] cross section passes through pool. [3] estimated from Manning's equation.
[2] estimated from on-site rating curve.

considerably narrower. In summer 1995, the moist zone at the Bucktail site (cross section (XS) 12+00 on July 26) was 0.6 foot, at the Steiner Flat site (XS 04+31 on August 8) it was 0.5 foot, and at the Sheridan Creek site (XS 02+35 on August 15) the zone was 0.4 foot.

Initiating narrow-leaf willow and shining willow seedlings were present as much as 1.5 feet above the low summer flow stage at the Pear Tree site (RM 73.1) (Figure 5.38) and 1.8 feet at the Deep Gulch site (RM 82.2) (Figure 5.39). At the Limekiln site, narrow-leaf willow ranged up to 1.0 foot above the low summer flow surface (Figure 5.40). All three sites had coarse gravel and cobble bed surfaces.

Successful seedling initiation occurred over a wider elevation range on bar surfaces the greater the distance below Lewiston. Unregulated tributary flows augment Lewiston releases in late spring and summer, pushing the capillary zone higher on the bars. By mid- to late summer, tributary flows decrease and Lewiston releases experience minor augmentation down to the Pear Tree site. Therefore, the capillary zone migrates over a greater range on bars farther downstream and encourages potentially wider bands of seedlings. For example, at the Pear Tree site, declining tributary inflows from June 1, 1996, through July 1, 1996, significantly modified the influence of Lewiston Dam releases on bar inundation. Although dam releases declined from 800 cfs the first week to approximately 500 cfs the last 3 weeks, flows at Pear Tree XS 15+00 (Figure 5.38) gradually declined from 1,200 to 600 cfs. On XS 15+00, the bar top was just inundated the first week of June. As flow gradually declined, the slow migration of the capillary zone provided a favorable environment for germination at stations 99 through 128. Without tributary influence, a steady flow of 500 cfs with a 0.5 foot capillary zone would create the same favorable environment only from stations 99 to 106. Fixed low-flow releases and lesser tributary flow contributions will produce a narrower band of favorable germination conditions closer to Lewiston Dam.



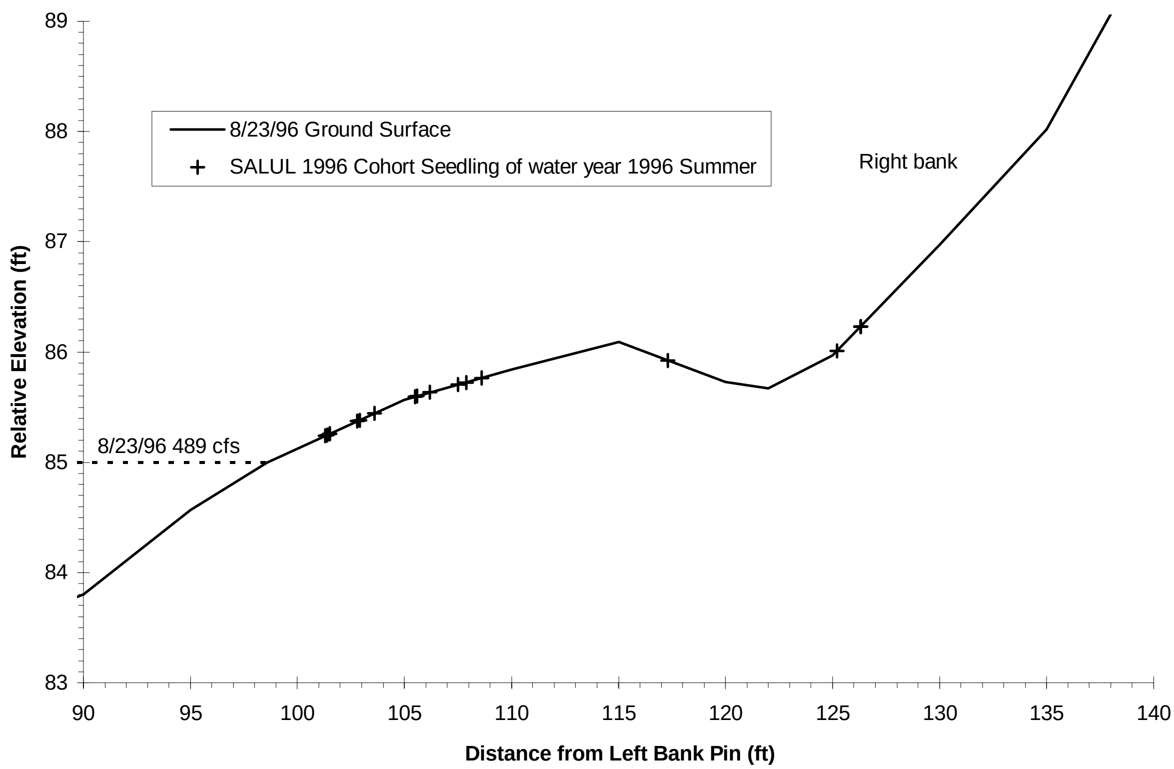


Figure 5.38. Pear Tree bank-rehabilitation site (RM 73.1) cross section 15+00, *Salix lucida ssp. lasiandra (*SALUL*)*, 1996 cohort, WY 1996 summer.

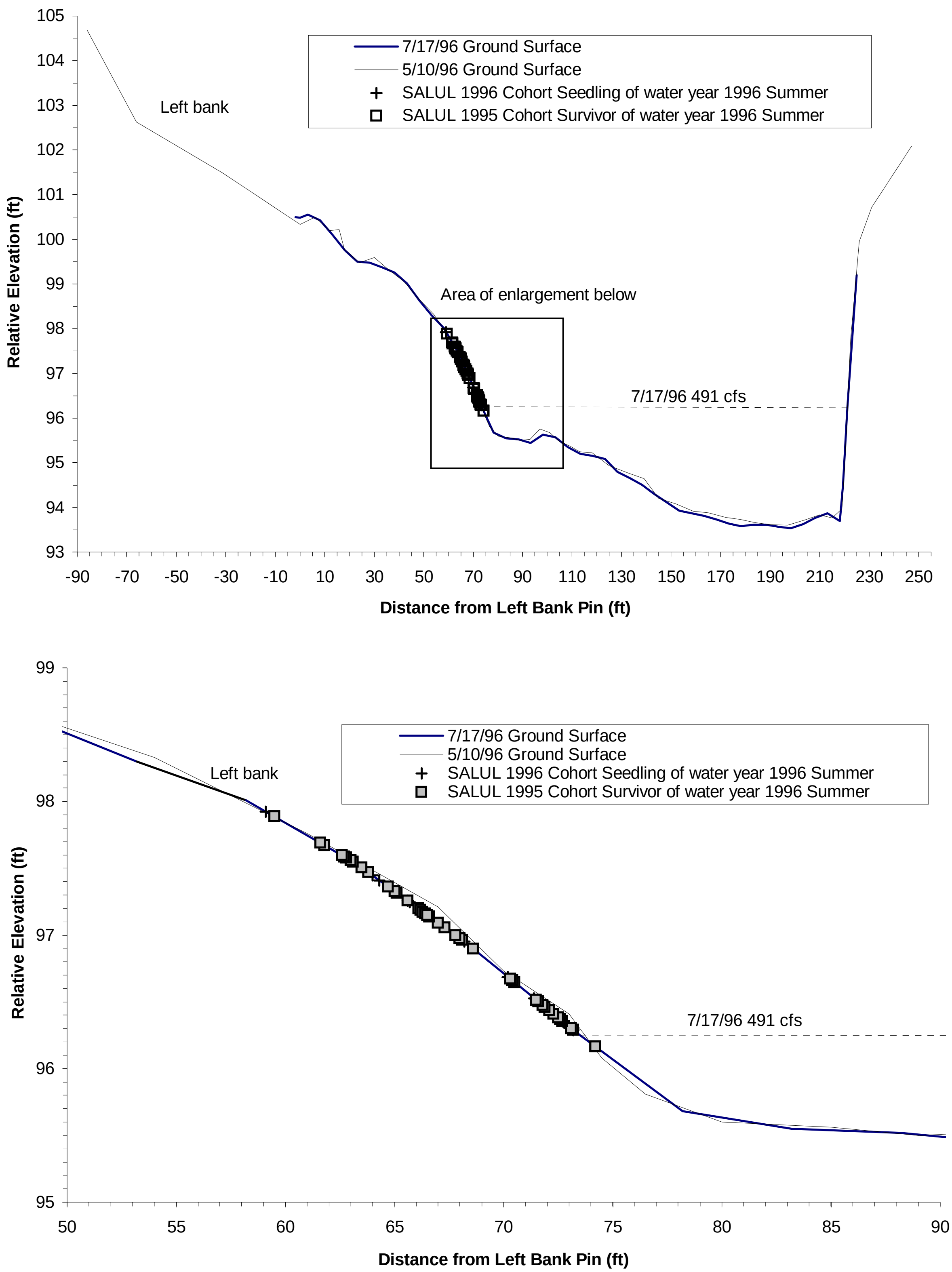


Figure 5.39. Deep Gulch bank-rehabilitation site (RM 82.2) cross section 13+90, *Salix lucida ssp. lasiandra* (SALUL), all cohorts, WY 1996 summer.

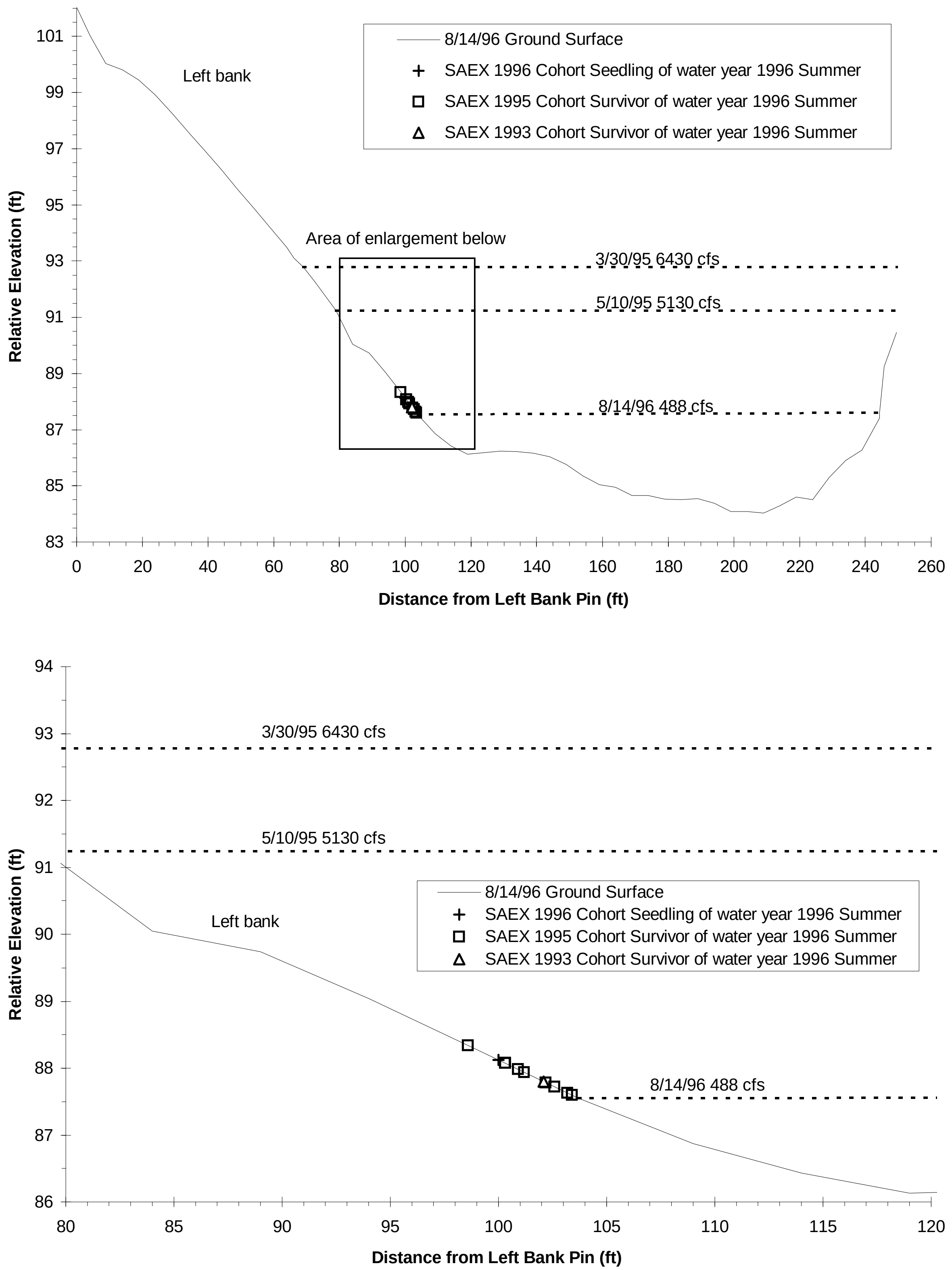


Figure 5.40. Limekiln bank-rehabilitation site (RM 100.2) cross section 11+86, *Salix exigua (*SAEX*)*, 1996 cohort, WY 1996 summer.

5.4.4.3 Subsurface Moisture in Alternate Bars

Once germination at the surface occurs, seedlings can establish only if adequate subsurface moisture is available. Subsurface-moisture measurements were made throughout late spring and summer 1997. Three sets of gypsum-block soil-moisture sensors were placed at the Bucktail, Steiner Flat, and Sheridan Creek sites. Subsurface-moisture readings were converted to soil-moisture tension, and presented as a percentage of field capacity (the maximum amount of water that can be held without draining). Subsurface-moisture contents just below the bar surfaces approached field capacity. On the Bucktail site, subsurface soil moisture close to the bar surface remained high into August (Figure 5.41).

5.4.4.4 Critical Rooting Depth

Critical rooting depth is the root depth necessary to anchor the plant. If the bed scours beyond critical rooting depth, the plant is physically scoured from the channelbed surface. Critical rooting depth was estimated as follows: on alternate bars where high discharges had winnowed sand and pea gravels near the base of the plants, stems were gently pulled by hand until root strength failed. The plant height, root collar diameter, and critical root depth were measured and plant age was estimated. Local pebble counts were conducted to relate critical rooting depth to the particle-size distribution of the channelbed surface.

Critical rooting depth for 6-month old plants was the depth of the channelbed surface layer at both the Steiner Flat and Sheridan Creek bank rehabilitation sites (Figure 5.42). The surface layer is defined as the diameter of D_{84} particles. The relation of critical rooting depth to age appears asymptotic for 2-year to 5-year old plants. The asymptotic relation suggests that critical rooting depth may be more a function of local environmental factors (e.g., depth to water table) than seedling age or size after 2-years. If the surface D_{84} at the Sheridan Creek Site (RM 82.0) were mobilized, 6-month-old seedlings would probably be completely scoured out, but only half of the year old seedlings would be scoured out. While Figure 5.42 may imply that plants older than 3 years can be removed by scour exceeding 2 D_{84} deep, this usually does not occur because as plants grow older: (1) their lateral roots intermesh with roots of adjacent plants and stabilize the substrate from scour; and (2) the plant above ground continues to grow and shields the channelbed from scouring forces to the point where sediment deposition rather than scour occurs. Therefore, periodically mobilizing bar surfaces greater than 2 D_{84}'s deep are required to scour plants within the 2-3 year window of opportunity. Otherwise, another riparian berm will likely form along the low water edge.

5.4.4.5 Removal of Mature Trees

Maturing trees tend to become established in stands or in riparian berms. As a stand matures, flood-flow hydraulic forces are modified. Flood flows capable of scouring a single tree isolated on a bar commonly are incapable of scouring the same sized tree in a stand. Often, modification of the hydraulic forces is so complete that the surface beneath a stand experiences aggradation rather than scour. This occurred in many mainstem reaches during the January 1997 flood. A stand can be undercut by lateral bank migration (Section 4.8, Attribute No. 6) or isolated from mainstem low-flow channels by channel avulsion (Section 4.8, Attribute No. 8). Unregulated alluvial rivers typically migrate during bankfull and higher discharges. Bank avulsion can occur during infrequent large floods. Individual mature trees along the edge of stands may be especially susceptible to scour.

Although the magnitudes of flow required to remove a mature tree, a stand, or a riparian berm have been speculated, no quantitative flow estimates have been offered. Aerial photographs taken before, during, and after the 1974 flood (14,000 cfs released from Lewiston Dam) show local disturbance to the riparian berm (Figures 4.24 to 4.26). The WY1997 flood below Rush Creek (approximately 11,000 cfs) locally scoured and

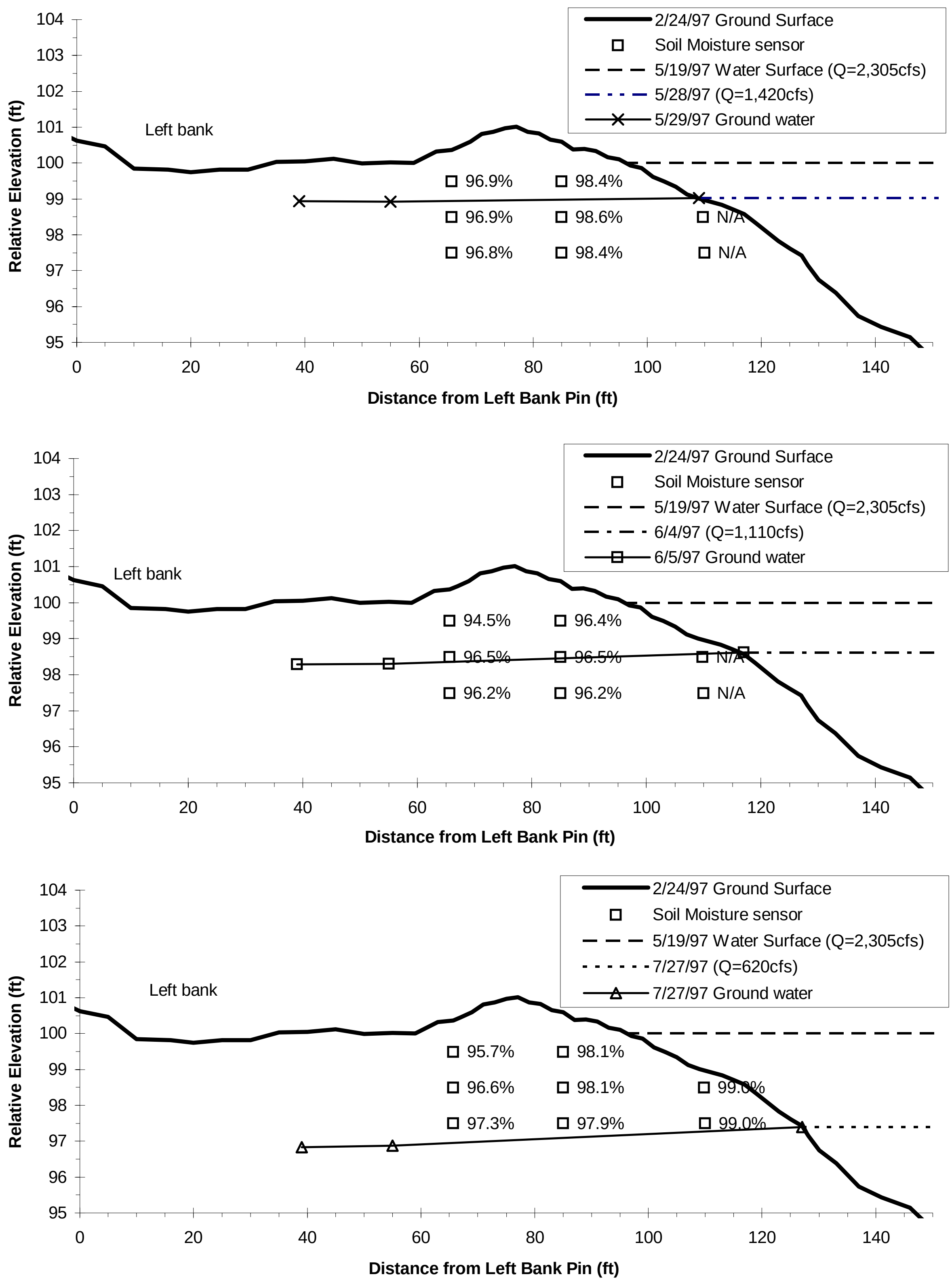


Figure 5.41. Bucktail bank-rehabilitation site (RM 105.6) ground water and soil moisture (as a percentage of field capacity) values, top: 5/28/97, middle: 6/5/97, bottom: 7/27/97.

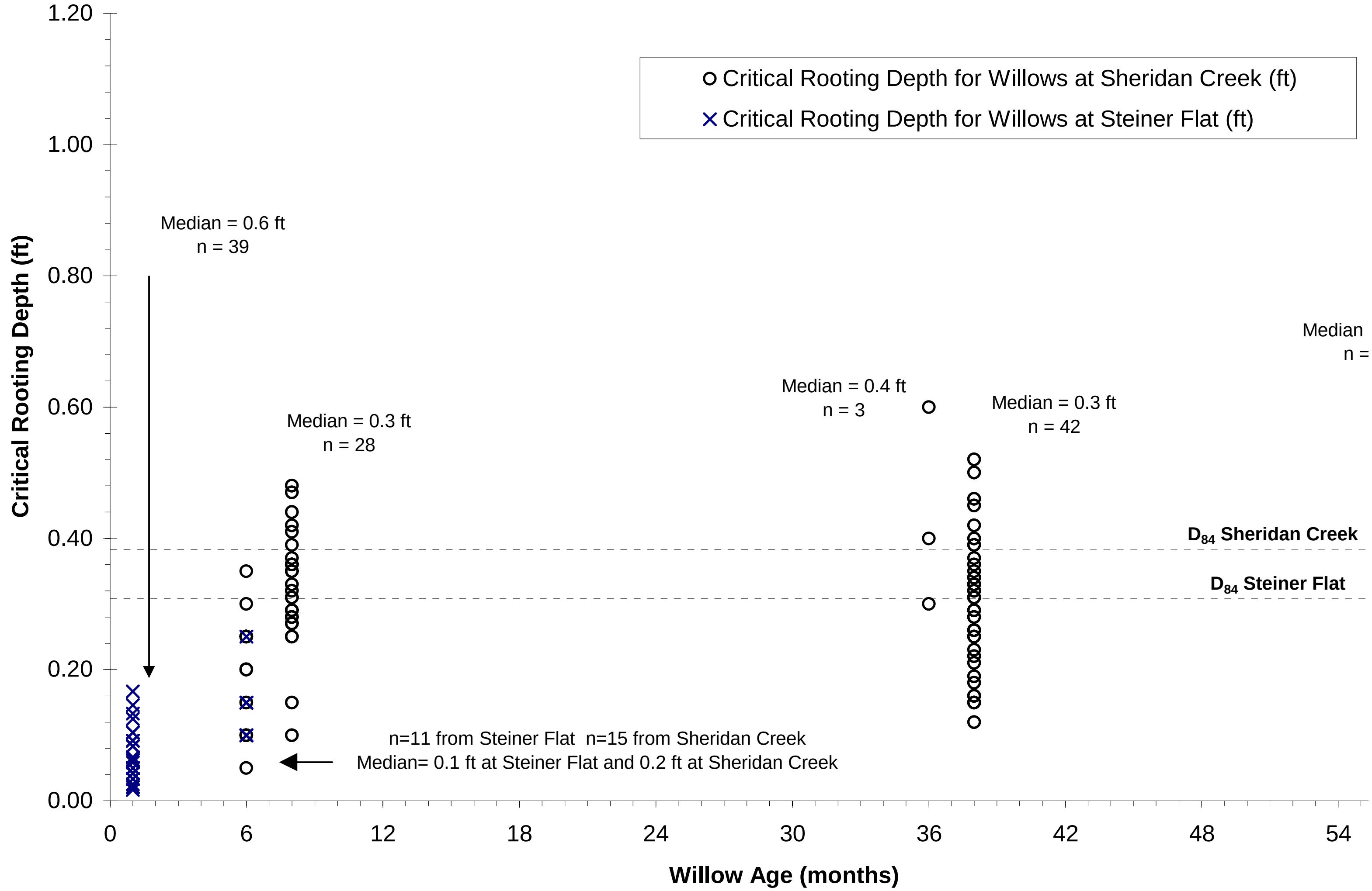


Figure 5.42. Critical rooting depth for willows of various ages, collected on exposed, active channel bed surfaces in the summer of 1995 and winter/spring 1996. Median values from each group sampled are given in millimeters. Two bank-rehabilitation sites were sampled: Steiner Flat (RM 91.8) and Sheridan Creek (RM 82.0). Sample size is indicated above each age by site. The D_{84} particle size represents summer 1998 conditions on point bar faces.

undercut a few mature trees in the riparian berm but it was not until the 1997 flows reached 30,000 cfs at Junction City when portions of the berm were removed completely. To estimate a flow threshold for scouring a mature tree, the critical moment required to topple a mature alder rooted in a riparian berm was estimated. The critical moment is synonymous to a critical torque, which is the product of a force acting on an object and the distance from the force to the point of rotational failure (in this case, the root mass). Critical moment was measured while toppling alders with a bulldozer.

Streamflows exceeding 14,000 cfs to 20,000 cfs would be required to remove the existing riparian berm, which is beyond the ability of controlled TRD streamflow releases.

Six alders (>20 years old) from a saturated portion of the riparian berm were mechanically toppled by a bulldozer at the Steiner Flat site (RM 91.8) in August 1995. The critical moment required to topple each alder in the riparian berm was measured using a tensiometer in line with the cable attached to the bulldozer. When the tree began to topple, force on the tensiometer was converted to a moment. Force exerted by the flow on the tree was computed for that given flow based on expected flood debris size (positioned against the upstream trunk) and flow velocity. The flow was incrementally increased until the force of the flow equaled the force (moment) measured in the field (see McBain and Trush, 1997, for assumptions, equations, and calculations).

Of the six trees toppled, four provided acceptable data for this analysis; equipment failure impaired the other two tests. The critical moments of failure for the four trees were: 54,000 ft-lbs (diameter at breast height = 0.80 foot), 97,600 ft-lbs (diameter at breast height = 1.0 foot), 100,000 ft-lbs (diameter at breast height = 1.1 feet), and 96,600 ft-lbs (diameter at breast height = 1.2 feet). The consistency of failure moments, particularly of the later three, provides reasonable confidence in the force required to push the trees over.

The estimated critical discharge for tree failure was primarily dependent on the size of debris pile lodged against the tree because the debris has a large surface area (larger coefficient of drag) and acts on the tree at the maximum distance from the rotation point (increases moment). Debris-pile dimensions were classified as follows: large debris (15 feet by 7.5 feet), small debris (10 feet by 5 feet), and a single log (8 feet by 2 feet). The range of predicted critical discharges is listed in Table 5.9. The small debris-pile class best approximates typical debris piles observed on the mainstem, suggesting that flows in the 14,000 to 20,000 cfs range are required to topple the most exposed mature alders. Larger flows would be required to topple most trees in the riparian berm up to a point at which the size of debris pile and the water elevation were sufficient to begin the domino effect on the remainder of the riparian berm.

5.4.4.6 Riparian Encroachment at Bank-Rehabilitation Sites

The pilot bank-rehabilitation projects provided newly exposed alluvial surfaces on which to observe initial stages of woody riparian colonization and possibly encroachment. Beginning in 1995, the Bucktail (RM 105.6), Steiner Flat (RM 91.8), and Sheridan Creek (RM 82.0) bank-rehabilitation sites were monitored to document woody riparian plant initiation and establishment. Five cross sections were surveyed at each site for band transect sampling. Density, frequency, bank position, annual cohort, and descriptive growth characteristics were measured for all sampled transects. After each winter high-flow period and each summer low-flow period, plant initiation and mortality were documented and related by plant abundance and bank position to annual growth stage of specific plant species, hydrograph

Table 5.9. Critical discharges needed to push over mature alders in a riparian berm as a function of debris size.

Debris Jam Classification	Debris Dimension	Alder #2 (D=0.8 ft) Discharge (cfs)	Alder #4 (D=1.0 ft) Discharge (cfs)	Alder #5 (D=1.1 ft) Discharge (cfs)	Alder #6 (D=1.2 ft) Discharge (cfs)
Large jam	15 ft x 7.5 ft	10,100	10,800	9,250	11,800
Small jam	10 ft x 5 ft	15,900	18,300	16,200	19,400
Single log	8 ft x 2 ft	31,800	41,000	37,000	42,100

component, and hydraulic geometry. Response of sampled plants was related to local fluvial processes during the water year (scour, inundation, etc.).

A simplifying assumption was that channelbed scour to depths less than the critical rooting depth would not impair survival. What was observed on the bars was not as straightforward. On January 8, 1996, we inspected the Sheridan Creek site following a 3,400-cfs peak flow in late December 1995. Willow seedlings of the WY1995 cohort were stressed, with roughly half their roots freshly exposed or removed (where the sand had been scoured from interstitial areas among larger particles). The channelbed had not reached a surface mobility threshold, although smaller particles (up to 1 $^{3}/_{16}$ inches) had moved. This event demonstrated that seedlings under age 1 could be killed or weakened by flows that fail to mobilize the entire surface layer of bars. A slightly higher discharge would presumably increase scour of the sand matrix as well as mobilize larger surface particles.

Annual channelbed dynamics were associated with narrow-leaf willow seedling initiation or establishment in WY1995 and WY1996 on three bank-rehabilitation sites. For the three sites, few narrow-leaf willows of the WY1995 and WY1996 cohorts survived into the summer of 1997 (Table 5.10). To interpret channelbed dynamics over these water years, the following annual hydrographs were utilized: Lewiston gage site for the Bucktail site (Figure 5.43); the Douglas City gage for the Steiner Flat site (Figure 5.44); and the Junction City gage for the Sheridan Creek site (Figure 5.45).

Streamflows exceeding 6,000 cfs to 8,500 cfs remove most new seedlings initiating on lower portions of point bars, while flows exceeding 10,000 cfs remove nearly 100% of new seedlings.

The Sheridan Creek site has a broad gently sloping right bank that annually supports abundant narrow-leaf willow seedlings. Willows germinated on the exposed bar surface down to low-water surface in WY1995, WY1996, and WY1997. For example, the upper portions of the newly formed bar surfaces were exposed in mid-June during narrow-leaf willow seed dispersal allowing widespread germination. The WY1995 cohort experienced channelbed mobilization its first winter. Discharge peaked near 8,500 cfs and mobilized at least the surface layer and portions of the subsurface. By May 1996, most had died. Although the Junction City gage did not survive the January 1, 1997, flood, peak discharge was estimated by indirect measurement to be 30,000 cfs, well above the threshold for significant subsurface scour. At Sheridan Creek, no willows from the three cohorts survived scouring on the open bar. A similar series of events occurred for willow cohorts at the Steiner Flat site, although 2 plants from the WY1993 cohort survived the January 1, 1997, flood (Table 5.10). At the Bucktail site, seedlings were killed by bar deposition, not scour. Further deposition resulting from the January 1, 1997 flood eliminated the WY1996 cohort.

Table 5.10. Narrow-leaf willow (*Salix exigua*) abundance at: (A) Sheridan Creek (RM 82.0) cross section 2+35; (B) Steiner Flat (RM 91.8) cross section 4+31; and (C) Bucktail (RM 105.6) cross section 12+00. NA = Not applicable.

A.	Narrow-leaf Willow (*Salix exigua*) Cohort Abundance							
	1995 Sample			1996 Sample			1997 Sample	
Annual Cohort	Spring	Summer 8/15/95	WY 96 Q_{peak} = 8,800 cfs	Spring 5/14/96	Summer 7/28/96	WY 97 Q_{peak} = 30,000 cfs	Spring 5/1/97	Summer
WY1993	NA	5		13	19		0	NA
WY1995	NA	5,207		192	114		0	NA
WY1996	NA	NA		0	914		0	NA
WY1997	NA	NA		NA	NA		0	NA

B.	Narrow-leaf Willow (*Salix exigua*) Cohort Abundance							
	1995 Sample			1996 Sample			1997 Sample	
Annual Cohort	Spring	Summer 8/8/95	WY 96 Q_{peak} = 7,300 cfs	Spring 5/4/96	Summer 7/26/96	WY 97 Q_{peak} = 24,000 cfs	Spring 4/30/97	Summer
WY1993	NA	0		0	1		2	NA
WY1995	NA	994		76	129		9	NA
WY1996	NA	NA		11	100		0	NA
WY1997	NA	NA		NA	NA		0	NA

C.	Narrow-leaf Willow (*Salix exigua*) Cohort Abundance							
	1995 Sample			1996 Sample			1997 Sample	
Annual Cohort	Spring	Summer 7/25/95	WY 96 Q_{peak} = 6,370 cfs	Spring 5/4/96	Summer 7/25/96	WY 97 Q_{peak} = 6,700 cfs	Spring 4/30/97	Summer
WY1993	NA	27		0	7		0	NA
WY1995	NA	1,444		57	19		0	NA
WY1996	NA	NA		1	1		0	NA
WY1997	NA	NA		NA	NA		0	NA

5.4.4.7 Conclusions

Narrow-leaf willow is the most common species establishing on exposed alluvial surfaces and the species most likely to encroach onto bank-rehabilitation sites. Without flow variability and large-magnitude floods to periodically eliminate vegetation near the water's edge and on bars, bank-rehabilitation sites along the mainstem can be expected to revert quickly to degraded conditions. Bar inundation to discourage and (or) constrain germination coupled with frequent channelbed surface mobilization is the most feasible approach to prevent widespread riparian encroachment. Bar inundation alone would not suffice. Once established willows reach their second and third years, removal with TRD releases become increasingly difficult because the lateral distribution, density, and interlocking of roots increases the plant's resistance to scour removal. By coordinating (1) critical rooting depth

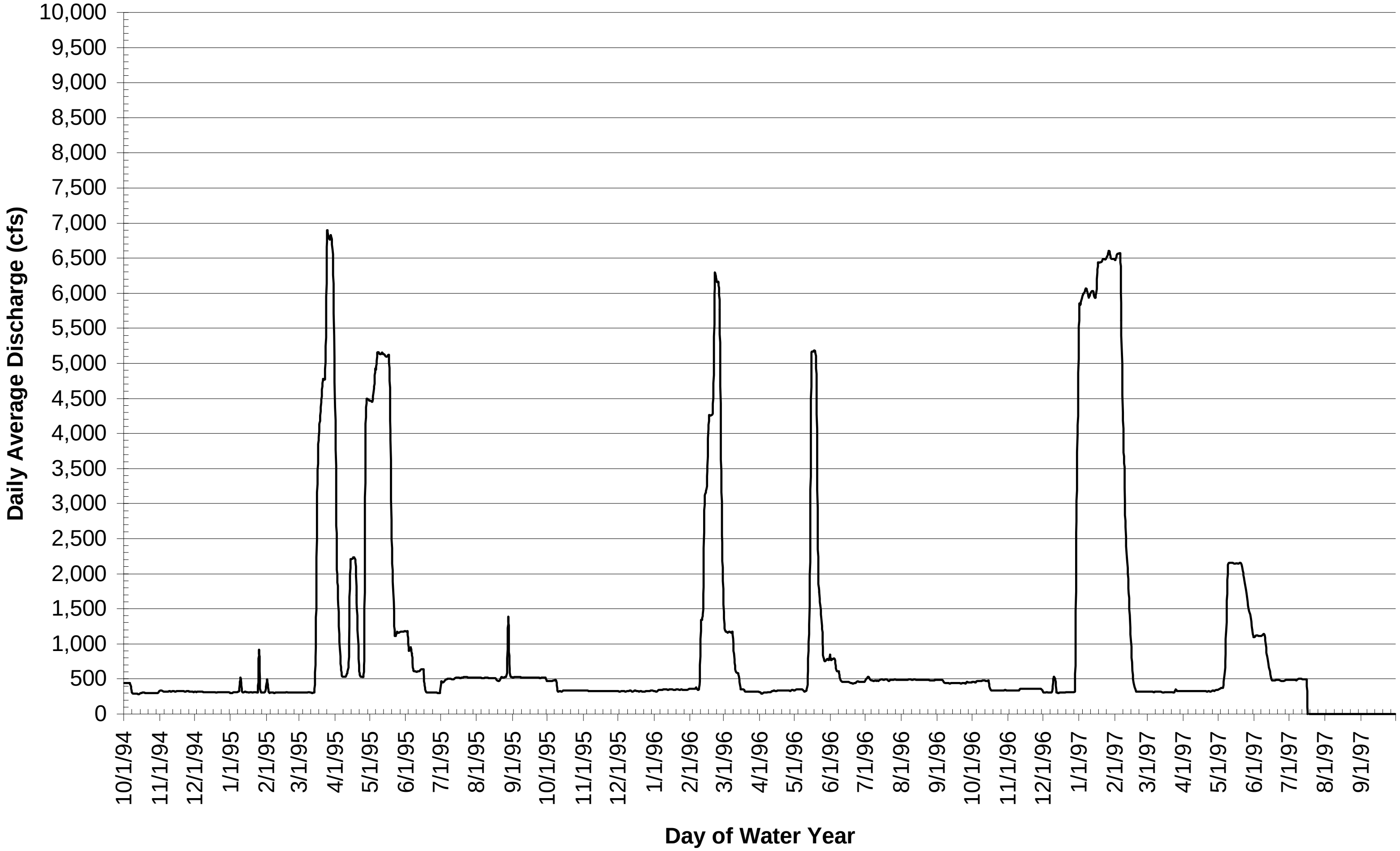


Figure 5.43. Trinity River at Lewiston (RM 110.9) daily average discharge for WY 1995-1997.

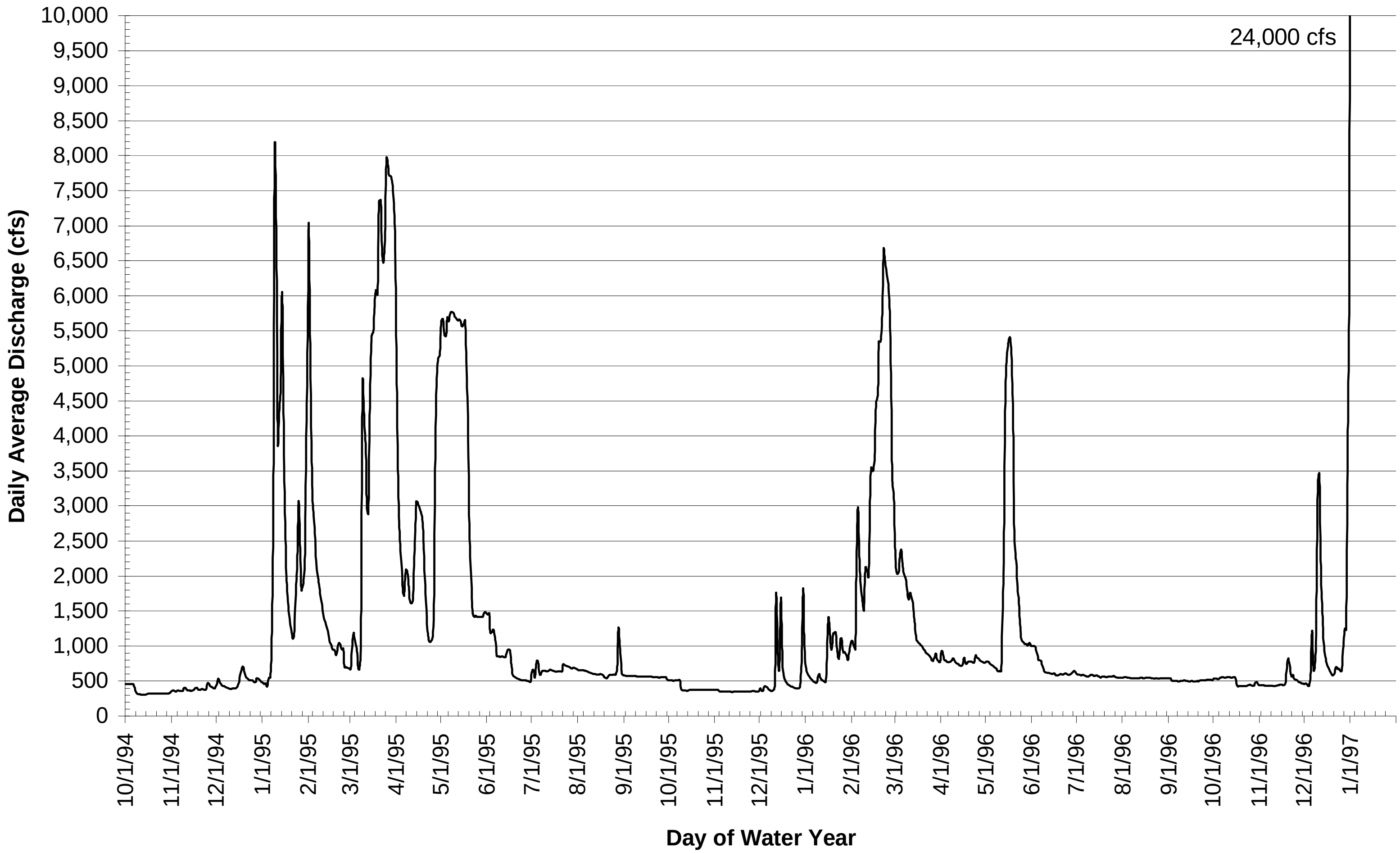


Figure 5.44. Trinity River near Douglas City (RM 92.2) daily average discharge for WY 1995-1997.

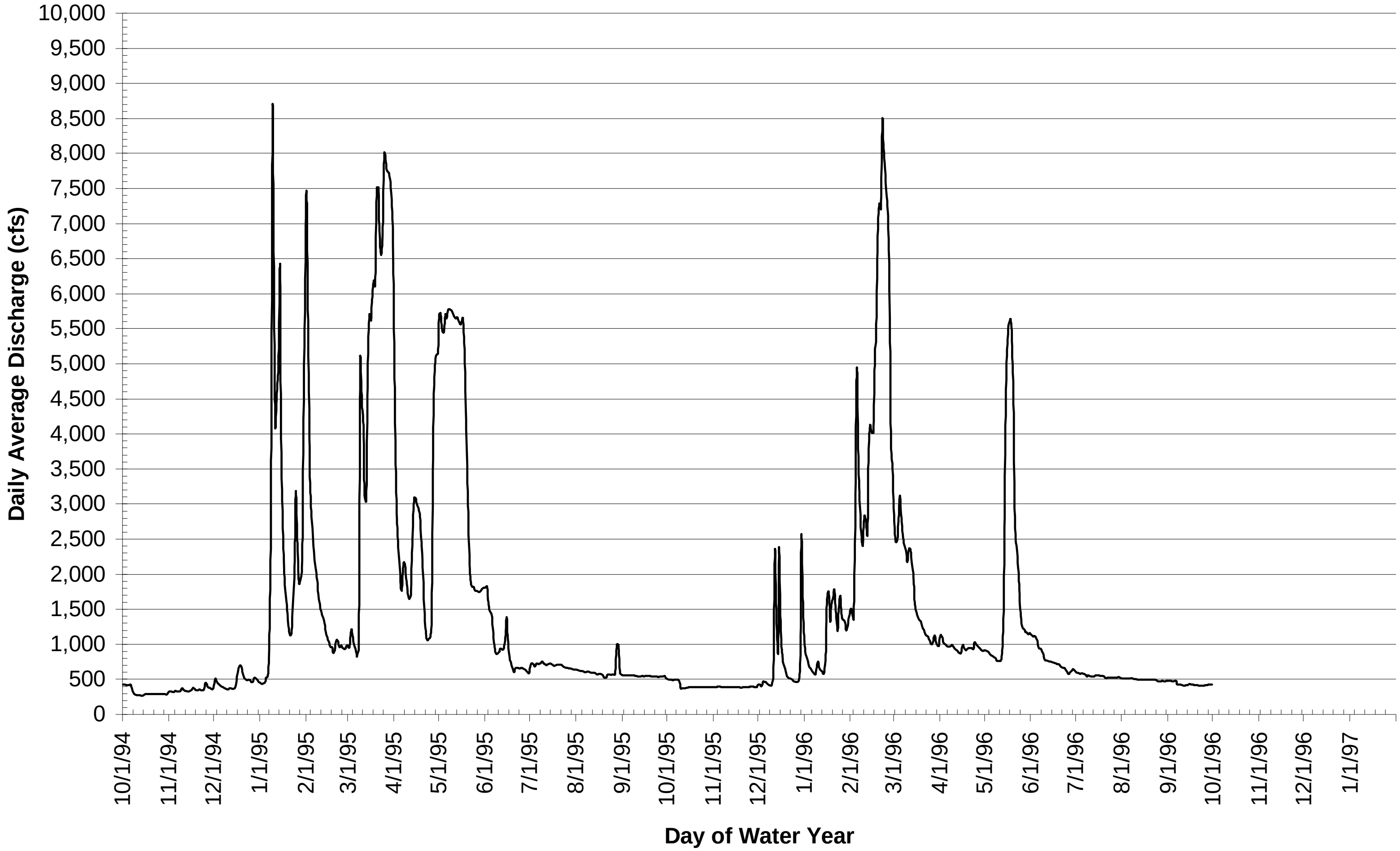


Figure 5.45. Trinity River at Junction City (RM 79.6) daily average discharge for WY 1995-1996.

and mobilization/scour predictions, (2) timing and magnitude of bar inundation, and (3) seasonal vertical migration of the capillary zone, Lewiston Dam releases can be tailored to induce mortality and thus discourage riparian encroachment. A peak flow threshold necessary to remove mature riparian trees within the riparian berm may begin at 14,000 cfs, but more realistically would require 16,000 to 20,000 cfs for single trees, and probably 30,000 cfs for local riparian berm removal. The WY1997 flood at Junction City, where peak flows reached 30,000 cfs, showed that riparian berms were tenacious; no riparian berm was entirely removed.

"Water temperature affects every aspect of the life of a fish, including incubation, growth, maturation, competition, migration, spawning, and resistance to parasites, diseases, and pollutants."

Lewiston Dam releases should also be tailored to encourage natural riparian regeneration on functional floodplains. Larger flows exceeding 8,500 cfs will encourage channel migration, floodplain formation, fine sediment deposition on floodplains, and scour channels on floodplains, all of which will provide favorable rooting conditions for riparian vegetation. Additionally, a gradually receding limb to the flood hydrograph will foster cottonwood survival on higher geomorphic surfaces by allowing their roots to track the receding capillary fringe (Mergliano, 1996; Rood and Mahoney, 1990; Segelquist et al., 1993).

5.4.5 Alluvial River Attributes: Summary

Other attributes described in Section 4.8 did not receive the attention that the attributes discussed above received. Attribute No. 1 is a sum of all other attributes. Presently, there is essentially no channel migration or functional floodplain to study. Therefore, Attributes No. 6 (periodic channel migration) and No. 7 (functional floodplain) will be important measurable responses in an adaptive environmental assessment and management plan and must be considered in mechanical channel rehabilitation. Attribute No. 8 (infrequent channel-resetting floods) may be key in generating future channel complexity. Without piggybacking dam releases onto tributary floods, the primary opportunity for tributary flood peaks exceeding 20,000 cfs will be below Indian Creek. McBain and Trush (pers. comm.) have been examining the physical effects of the January 1997 flood on the riparian berms and terraces. Attribute No. 10 has not been addressed. Groundwater recharge in the floodplain is an unknown, and needs to be investigated. Off- channel wetlands aren't known to exist in the floodplain corridor that has been essentially excavated between the valley walls during gold mining, although a few scour channels have off- channel depressions. These are also being investigated by McBain and Trush. The role of the snowmelt recession limb in sustaining seasonal wetlands and scour channels for aquatic organisms deserves close examination in the future.

5.5 Flow-Temperature Relations

5.5.1 Introduction

Water temperature affects every aspect of the life of a fish, including incubation, growth, maturation, competition, migration, spawning, and resistance to parasites, diseases, and pollutants (Armour, 1991). This section describes temperature–flow relations in the Trinity River through the use of a water-temperature model and empirical data. Simulation results were used to: (1) recommend dam releases that maintain water temperatures suitable to protect outmigrating steelhead, coho salmon, chinook salmon smolts; (2) recommend releases to protect holding and spawning adult chinook salmon (i.e., meet California Regional Water Quality Control Board - North Coast Region (CRWQCB-NCR) temperature targets); and (3) evaluate flow–temperature relations conducive to juvenile salmonid growth.

Since construction of the TRD, the magnitude, timing, and duration of flows downstream from Lewiston have been dramatically altered; consequently, seasonal temperature regimes have changed (see Section 4.3.6). The storage of snowmelt runoff from the watershed above the dams has resulted in warmer springtime water temperatures throughout the Trinity River below Lewiston than in comparison with pre-TRD temperatures (TRBFWTF, 1977). Summer and fall water temperatures at Lewiston have become colder as a result of operations of upstream dam facilities that release water from the cold lower stratum (hypolimnion) of Trinity Lake (TRBFWTF, 1977). An additional consequence of dam operations is that wintertime water temperatures near Lewiston are now warmer than pre-TRD.

"Since construction of the TRD, the magnitude, timing, and duration of flows downstream from Lewiston have been dramatically altered; consequently, seasonal temperature regimes have changed."

5.5.1.1 Temperature Effects on Smoltification

Parr-smolt transformation (smoltification) during the spring involves changes in the behavior and physiology of juvenile anadromous salmonids that prepare them for survival in salt water (Folmar and Dickhoff, 1980; Wedemeyer et al., 1980). Environmental cues such as increasing photoperiod (day length) and water temperature (warming trend) stimulate production of Na^{+}-K^{+} ATPase (ATPase), an enzyme associated with smoltification (Zaugg and Wagner, 1973; Zaugg and McLain, 1976). Although photoperiod and water temperature are primarily responsible for initiating smoltification in juvenile coho salmon and steelhead, studies suggest that water temperature alone is the primary influence on the timing and duration of emigration and smoltification of chinook salmon (Folmar and Dickhoff, 1980; Wedemeyer et al., 1980; Hoar, 1988).

In all three species, water temperature acts as a modifier of physiological responses to photoperiod; when water is slow to warm in the spring, the ATPase activity is extended and smolts emigrate over a longer time period (Hoar, 1988). The extended migration periods associated with gradual warming may result in increased growth, a benefit because larger smolts have higher survival rates in seawater (Hoar, 1988). Conversely, if water temperatures warm quickly in the spring ATPase activity shortens, allowing smolts less time to migrate to seawater (Wedemeyer et al., 1980; Hoar, 1988). Klamath River estuary studies conducted by the California Department of Fish and Game (Wallace and Collins, 1997) found juvenile chinook salmon to be significantly larger in 1993, when water temperatures upstream from the estuary were cooler, in comparison with a similar time period of warmer water temperatures in 1994.

If smolts do not reach seawater while physiologically ready for seawater adaptation, they revert to parr, and migratory behavior diminishes (Hoar, 1988). Parr may again smolt when water temperature and photoperiod again become favorable either in the fall or the following spring (Hoar, 1988). Survival of parr in freshwater, however, may be jeopardized if they are subjected to poor water quality, competition, or predators (Cada et al., 1997).

Water temperatures that are known to interrupt the smoltification process vary by species and are primarily known from controlled experiments (See reviews by Wedemeyer et al., 1980; and Folmar and Dickhoff, 1980). From literature reviews, Zedonis and Newcomb (1997) identified three categories of thermal tolerance for salmonid smolts in the Trinity River (Table 5.11). The three categories – optimal, marginal, and

Table 5.11. Water temperature requirements for steelhead, coho salmon, and chinook salmon smolts (Values are from Zedonis and Newcomb (1997)).

Species	Category of Thermal Tolerance [a]	Water Temperature (°F)	Source
Steelhead	Optimal	42.8 to 55.4	Zaugg and Wagner (1973), Adams et al (1973), Zaugg et al. 1972
	Marginal	55.4 to 59	Kerstetter and Keeler (1976), Zaugg et al. (1972)
	Unsuitable	> 59	Adams et al. (1973), Zaugg et al. (1972)
Coho Salmon	Optimal	50 to 59	Clarke (1992)
	Marginal	59 to 62.6	Clarke (1992)
	Unsuitable	> 62.6	Clarke (1992)
Chinook Salmon	Optimal	50 to 62.6	Clarke (1992), Clarke and Shelbourne (1985)
	Marginal	62.6 to 68	Inferred between Clarke (1992) and Baker et al. (1995)
	Unsuitable	> 68	Baker et al. (1995)

[a] Categories of Optimal, Marginal, and Unsuitable refer to the relative likelihood of maintaining smoltification.

unsuitable – were defined by the relative likelihoods that smolts will revert to parr or lose their ability to hypoosmoregulate (osmoregulate in seawater).

Steelhead have been the subject of many experiments that examined the relation between water temperature and smoltification. Zaugg and Wagner (1973) concluded that water temperatures greater than 55.4° F may interfere with steelhead parr-smolt transformation. Zaugg (1981) also observed a reduction in migratory tendencies under natural photoperiod conditions after steelhead were exposed to water temperatures of 55.4° F for 20 days versus those exposed to 42.8° F. Kerstetter and Keeler (1976) found that water temperatures near 59° F were responsible for reduced gill ATPase activity in TRFH steelhead. They further speculated that high springtime water temperatures were responsible for sharp declines in the number of wild migrating steelhead smolts captured in traps during the spring in the lower Trinity River at Weitchpec.

Coho salmon smolts also require cool water temperatures to smolt. Zaugg and McLain (1976) found that elevated freshwater temperatures (59° and 68° F) shortened the period of elevated ATPase levels in comparison with that of fish reared in 42.8° and 50° F freshwater. They also found that coho salmon reared at a constant water temperature (42.8º F) maintained elevated ATPase levels through July, but when these fish were exposed to warmer water temperatures, their ATPase levels initially increased and then declined (gradually at 50º F, more quickly at 59º F , and rapidly at 68º F). Conversely, Zaugg and McLain (1976) demonstrated that ATPase levels increased when coho salmon reared in 59º F water were transferred into lower water temperatures. Clarke et al. (1981) found that the ability to hypoosmoregulate was greater for coho salmon reared in freshwater at 50º F versus 59º F. More recently, Clarke (1992) recommended rearing coho salmon at temperatures between 50º F and 59º F and reported that water temperatures below 62.6º F are required for survival in seawater.

In the Trinity River, chinook salmon smolts emigrate later in the spring than do either coho salmon or steelhead smolts, and typically encounter the warmest water temperatures (USFWS, 1998). In hatchery experiments, water temperatures warmed to 51.8º to 53.6º F were shown to support chinook smoltification (Muir et al., 1994). Clarke and Shelbourn (1985) found that chinook salmon reared in freshwater between 50º F and 62.6º F displayed the best ability to hypoosmoregulate. Baker et al. (1995) used data obtained over an 8-year period from 15 release groups of hatchery fall-run chinook salmon smolts to model smolt mortality under natural conditions as they migrated through a portion of the Sacramento–San Joaquin Delta. The estimated survival rate for smolts emigrating in water temperatures of 73.4º F was only 50 percent, whereas smolts emigrating in 68º F water experienced 90 percent survival. The results of their analysis corresponded well with prior laboratory studies (Brett, 1952) to determine the temperature at which 50 percent mortality is observed for a given acclimation temperature.

5.5.1.2 Smolt Emigration and Flow

Not only does increased flow have an effect on water temperature and smoltification, but it also reduces the travel time of smolts to seawater and thus increases survival rates (Bell, 1991). The physiological changes that

"Not only does increased flow have an effect on water temperature and smoltification, but it also reduces the travel time of smolts to seawater and thus increases survival rates."

a smolting salmonid undergoes reduce its swimming stamina, making emigration a relatively passive behavior (Folmar and Dickhoff, 1980). Because smolts often exhibit this passive emigration behavior, the increased average water velocities associated with increased flows transport the fish more quickly to the ocean, making chances of survival in seawater greater (Cada et al., 1997). Kjelson and Brandes (1989), using 10 years of data, found a strong correlation between estimated smolt survival rates, increased flow, and reduced water temperature in the Sacramento River. In the Snake River, peak emigrations of wild spring chinook salmon coincided with peak river flow (Achord et al., 1996), and in the Columbia River, flow was significantly correlated to the rate of chinook salmon smolt emigration (Raymond, 1979; Brege et al., 1996; Giorgi et al., 1997). Achord et al. (1996) suggested that increased releases after mid-May could benefit emigrating chinook smolts by increasing emigration rates. Cada et al. (1997), in a fairly extensive review of the literature, concluded that a positive relation between increased flows and smolt survival was a reasonable conclusion on the basis of the scientific evidence.

5.5.1.3 Trinity River Smolt Emigrations

Smolt emigration timing for steelhead, coho salmon, and chinook salmon in the Trinity River varies by species (Figure 5.46) (Zedonis and Newcomb, 1997; USFWS, 1998). From 1992 to 1995, at least 80 percent of steelhead, coho salmon, and chinook salmon smolts passed the Trinity River trap site near the town of Willow Creek (RM 21.1) by May 22, June 4, and July 9, respectively (Figure 5.46 B, C, D) (USFWS, 1998). In 1992 and 1994, years when water temperatures were warmer, chinook salmon appeared to migrate past the trap 1 to 2 weeks earlier (See Figures 5.46 A and D).

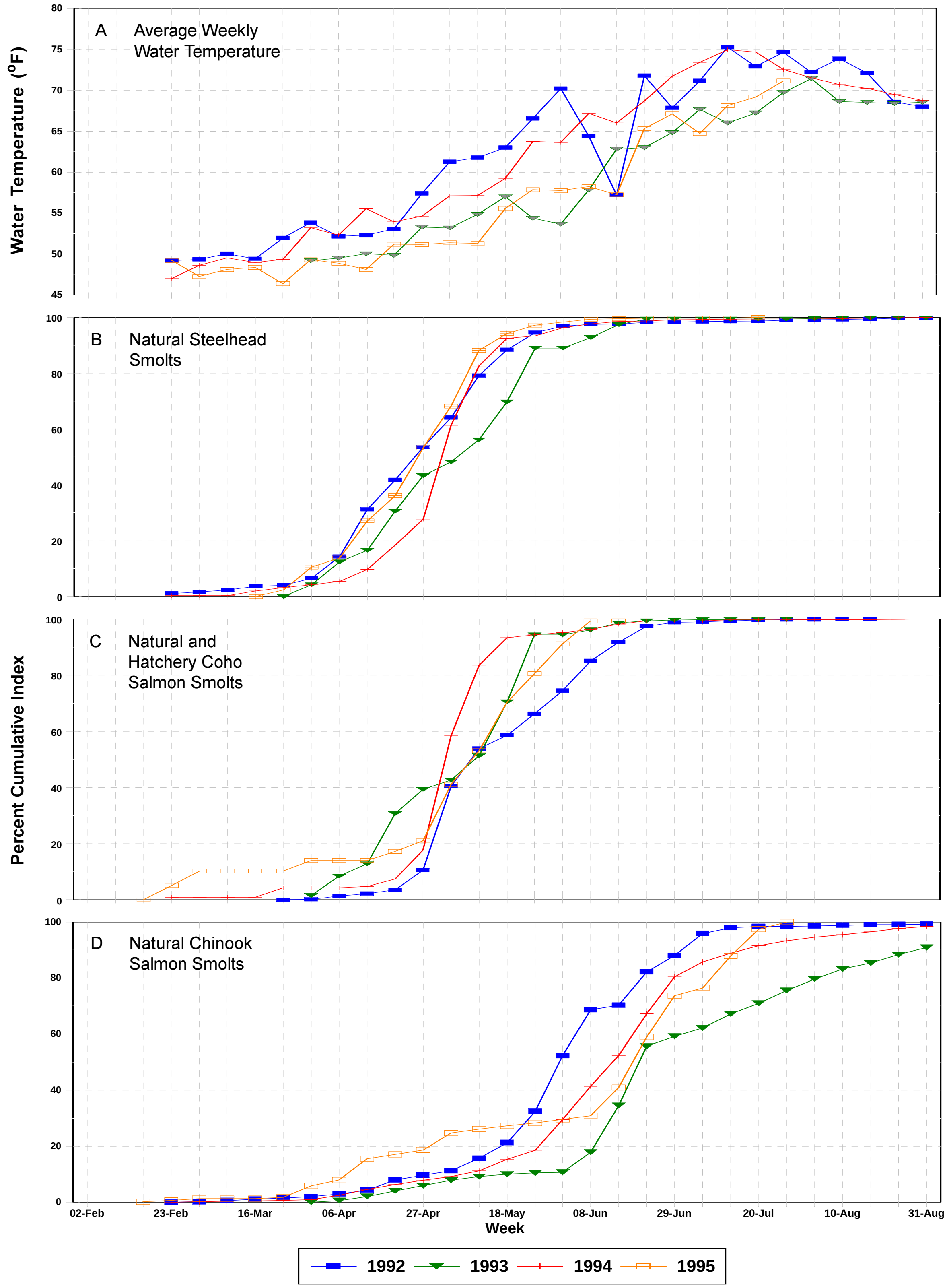


Figure 5.46. Average weekly water temperatures and cumulative abundance indicies for emigrating natural steelhead, natural and hatchery coho salmon, and natural chinook salmon. Data collected at the Willow Creek trap (RM 21.1) on the Trinity River, 1992 to 1995. Data collected by the USFWS, Arcata, CA.

5.5.1.4 Adult Salmon Holding and Spawning

Early-arriving adult salmon and steelhead require cold water temperatures to survive. During the spring, summer, and fall, adult chinook salmon and steelhead immigrate to areas below Lewiston Dam, and hold until the onset of spawning. In the absence of appropriate water temperatures, several direct and indirect factors can lead to poor survival of adults and developing eggs. In a literature review, Boles (1988) concluded that water temperatures between 38º and 60º F were adequate for protection of holding adults; at water temperatures above 60º F, prespawning mortality and temperature-mediated diseases or reduced egg or sperm viability can occur. During spawning, however, a water temperature less than or equal to 56º F is recommended to decrease the prevalence of infectious diseases and fungus (Ordal and Pacha, 1963, as cited by Boles, 1988). In response to these water-temperature requirements, the CRWQCB-NCR, with assistance from CDFG, NMFS, Hoopa Valley Tribe, and the Service, established water-temperature objectives for the first 40 miles below Lewiston Dam (Table 5.12) (CRWQCB-NCR, 1994).

> "In the absence of appropriate water temperatures, several direct and indirect factors can lead to poor survival of adults and developing eggs."

5.5.1.5 Temperature Effects on Juvenile Salmonid Growth

Salmonid growth is highly influenced by water temperature and food availability. At very low water temperatures, fish exhibit little or no growth, and require very little food to sustain bodily functions. As water temperatures increase, digestive enzyme efficiency increases, and depending on food abundance and quality, growth rates increase (Rich, 1987). Under laboratory conditions and maximum food rations, the water temperature at which maximum growth occurs is higher than for fish fed lower rations such as those found in natural stream settings (DEQ, 1995). At very high temperatures, however, excessive metabolic activity and synergistic effects of additional stresses (e.g., low dissolved oxygen) can result in little or no growth, disease, or death (DEQ, 1995). Lower lethal, upper lethal, and preferred temperatures (ºF) for rearing juvenile chinook salmon, coho salmon and steelhead are provided in Table 5.13. Preferred water temperatures are close to the optimum for maximum growth efficiency (Groot and Margolis, 1991).

> A water-temperature model (SNTEMP) and empirical water-temperature data were used to develop release recommendations to meet the temperature needs of anadromous salmonids of the Trinity River.

5.5.2 Methods

A water-temperature model of the Trinity River was used to investigate influences of Lewiston Dam releases on downstream water temperatures during the spring, summer, and fall months. The model uses the Stream Network Temperature Model (SNTEMP) (Theurer et al., 1984) as its foundation, and is a 7-day average daily model (Zedonis, 1997). Given a Lewiston Dam release and water temperature, the model can predict mainstem temperatures at any location downstream from Lewiston Dam to the confluence with the Klamath River, a distance of approximately 112 river miles (Zedonis, 1997). Comparison of observed and predicted water temperatures at three sites (Douglas City, Confluence of the North Fork Trinity River, and Weitchpec Falls) indicated that the model predicted temperatures well (Figures 5.47, 5.48, and 5.49). Following calibration, the model proved accurate to -0.70º + 2.93º F at the 90 percent confidence interval, throughout the river.

Table 5.12. Water temperature objectives for the Trinity River during the summer, fall, and winter as established by the CRWQCB-NCR.

Date	Temperature Objective (ºF)	
	Douglas City (RM 93.8)	North Fork Trinity River (RM 72.4)
July 1 through Sept 14	60	-
Sept 15 through Sept 30	56	-
Oct 1 through Dec 31	-	56

The SNTEMP model requires the input variables of dam discharge and release-water temperatures to predict downstream water temperatures. Dam discharge is reliably known, but the Lewiston Dam release-water temperatures can vary substantially depending on trans-basin diversions, releases to the Trinity River, and meteorology (e.g., air temperature and relative humidity). As described in Section 4.3.6, increased diversions and releases down the Trinity River act synergistically to maintain cold Lewiston Dam release water temperatures by shortening the residence time of water in Lewiston Reservoir.

5.5.2.1 Hypothetical-Year Type Simulations

Three hypothetical-year types, representing hot-dry, median, and cold-wet hydrometeorological conditions, were modeled (Zedonis, 1997). Each year type consisted of 52 independent weeks of hydrological and meteorological variables having differing exceedence probabilities (Table 5.14). Exceedence levels for these variables were determined from 27 years of weekly data (1965 to 1992). Thus, these year types are not used to evaluate a year as a whole (i.e., one would not expect to observe consecutive weeks of these conditions over a long period of time), but are used to show the sensitivity of combinations of variables (e.g., meteorology, tributary accretion, and dam release magnitude and release temperature) on water temperatures.

From April 1 to July 15, water temperatures of the Trinity River from Lewiston Dam to the confluence with the Klamath River at Weitchpec were evaluated with Lewiston Dam releases that ranged from 150 to 6,000 cfs. Evaluations of flow–temperature relations during this time period used the 7-day average minimum water temperature observed at the Lewiston gage (located 1.0 mile below Lewiston Dam) from 1987 to 1994. Minimum release temperatures were used to reflect cold release temperatures that would be present with high Lewiston Dam releases (e.g., 2,000 cfs) and the typically large diversions (2,000 to 3,600 cfs) that occur from April through July (Paul Fujitani, pers. comm.).

Temperature–flow relations during the summer and fall, a time when the CRWQCB-NCR objectives are in effect, were evaluated with 7-day average maximum and minimum water temperatures observed below Lewiston Dam from 1987 to 1994. Dam releases ranging from 150 to 1,000 cfs were evaluated under hot-dry, median, and cold-wet year type conditions. Both minimum and maximum release temperatures were evaluated to reflect varied diversion patterns and reduced Trinity River flows, typically 450 cfs, that may result in a wide range of release water temperatures. Because the CRWQCB-NCR objectives have been in effect since 1992, empirical data also are available from which to ascertain releases and release temperatures needed to meet the objectives.

Table 5.13. Lower lethal, upper lethal, and preferred temperatures (°F) for selected species of juvenile salmonids. Incipient lethal temperature (ILT) refers to abrupt transfer of fish between waters of different temperatures.

Species	Lethal Temperatures (°F)		Preferred Temperature (°F)	Source	Method
	Lower	Upper			
Chinook Salmon	33.4[a]	77[b]	53.6 to 57.2	Brett (1952)	ILT
Coho Salmon	35.0[a]	76.1[b]	53.6 to 57.2	Brett (1952)	ILT
Steelhead	32.0	75.0	50 to 55.4	Bell (1991)	

[a] Acclimation temperature was 50 F and no mortality occurred in 5,500 minutes.

[b] Acclimation temperature was 59 F and 50% mortality occurred in 10,000 minutes (1 week).

In addition to the above analyses, longitudinal water-temperature profiles were developed for releases that ranged from 50 to 6,000 cfs. These simulations were used to identify how releases influence the numbers of river miles that are within or near the preferred temperature range of juvenile salmonids during the spring and summer.

5.5.2.2 Historical-Year Type Simulations

Simulations for hydrometeorological conditions of WY1975 through WY1994 also were used to identify how release flows and release temperatures affect meeting water-temperature criteria in Tables 5.11 and 5.13. Release-water temperatures used in SNTEMP were simulated using a two-dimensional reservoir water quality model called the Box Exchange Transport Temperature and Ecology of a Reservoir (BETTER) model (Kamman, pers. comm; Trinity County, 1992). The BETTER model accounts for operations of the Trinity River Division (e.g., diversions and Trinity Dam release-water temperatures) and represents the most accurate prediction of release temperatures currently available. Simulated temperatures were generated for each representative year of the five water-year classes. Predicted release temperatures were then used for similar year types using SNTEMP to simulate river temperature conditions for the 20-year record (Table 5.15). Simulated annual release-water temperatures for representative years are illustrated in Figure 5.50.

5.5.3 Results

5.5.3.1 Hypothetical-Year Type Simulation

Simulations show that release magnitudes and meteorological conditions do not have a significant influence on river water temperatures during early April, but have a substantial influence as tributary accretion decreases and meteorological conditions warm from May to mid-July (Figure 5.51 and 5.52). This influence is particularly noticeable during hot-dry conditions. When discharge is at approximately 2,000 cfs or greater, water temperatures are less variable between year types. For example, water temperatures at Weitchpec would range from 61° to 63 °F for all three year types (hot-dry, median, and cold-wet) on July 1 with a dam release of 2,000 cfs (Figure 5.53). As releases are increased to 6,000 cfs, the effects of meteorology and tributary accretion are minimized.

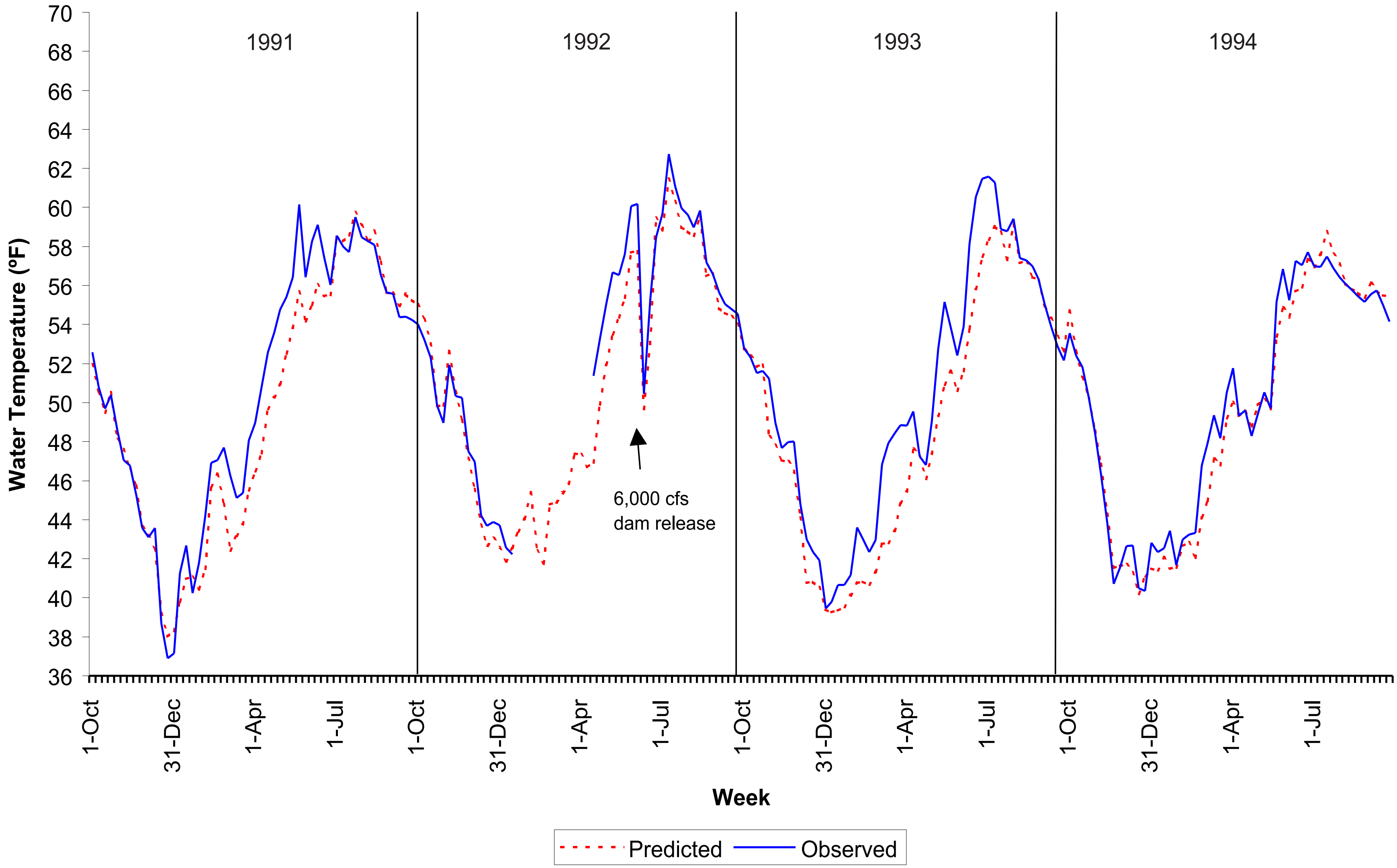


Figure 5.47. Trinity River water temperature model calibration results, 1991 through 1994. Predicted and observed water temperatures at Douglas City (RM 93.7).

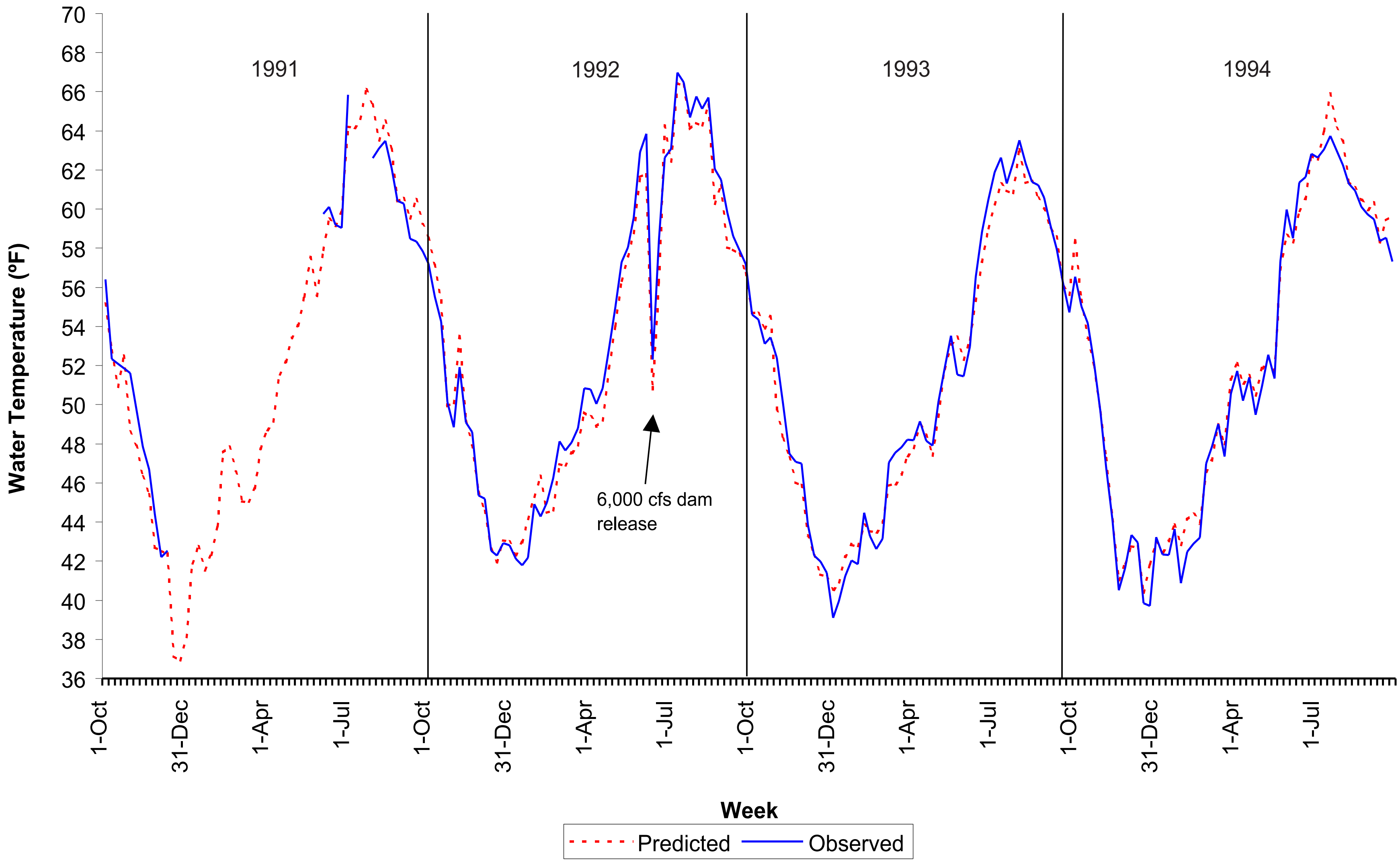


Figure 5.48. Trinity River water temperature model calibration results, 1991 through 1994. Predicted and observed water temperatures near the confluence of the North Fork Trinity River (RM 73.8).

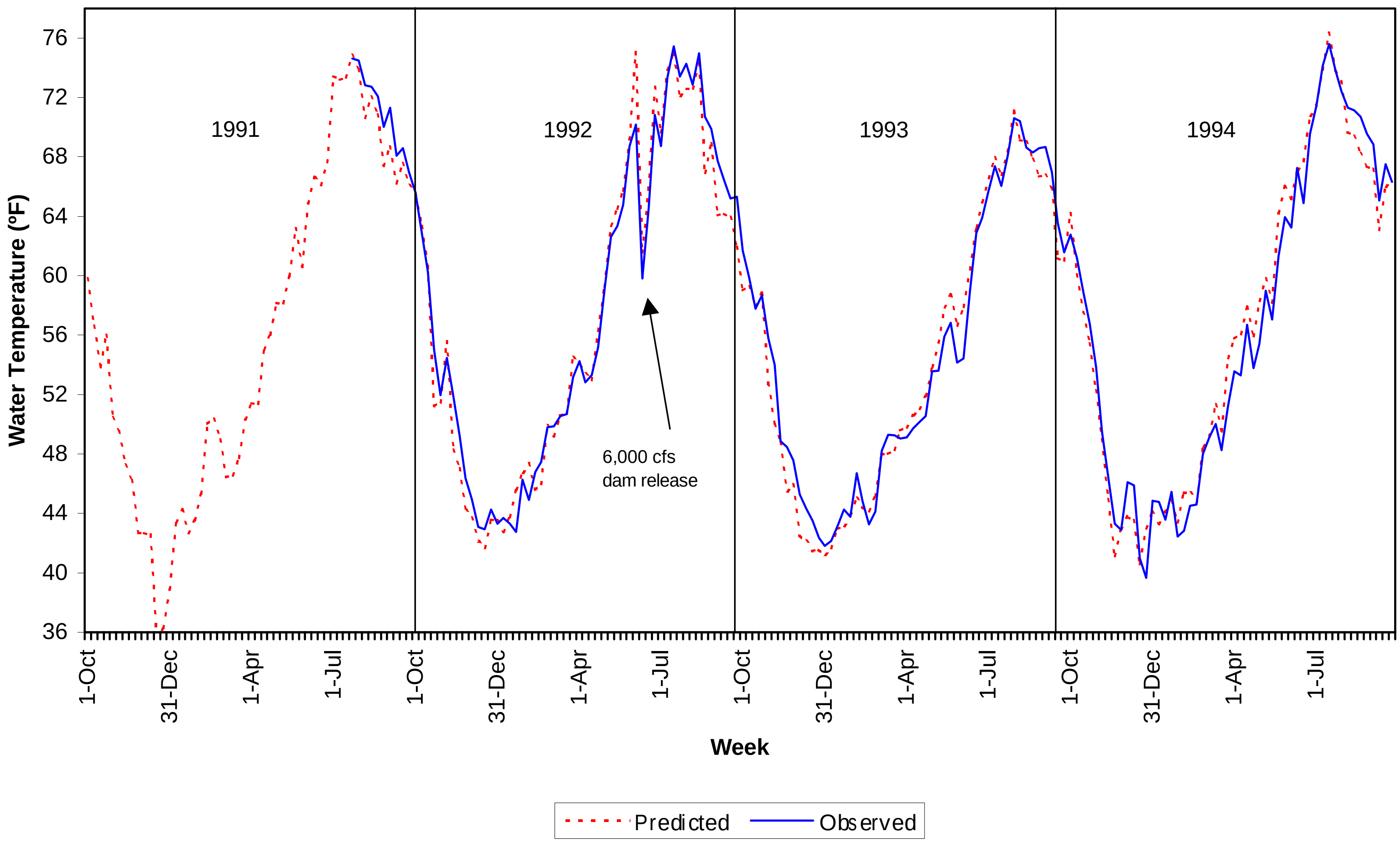


Figure 5.49. Trinity River water temperature model calibration results, 1991 through 1994. Predicted and observed water temperatures at Weitchpec Falls (RM 0.7).

Table 5.14. Hydrometeorological components of hypothetical year types as a function of percent probability of exceedance.

Variables	Hypothetical Year Types		
	Hot-dry	Median	Cold-wet
Meteorologic			
Air temperature	10	50	90
Percent Possible Sun	10	50	90
Wind Speed[a]	50	50	50
Relative Humidity	90	50	10
Hydrologic			
Tributary Accretion	90	50	10

[a] Because of the low sensitivity of wind speed on water temperatures, this variable was the same for all year types.

Empirical data show that large releases in June 1992 resulted in reduced water temperatures throughout the entire mainstem Trinity River (Zedonis, 1997). An experimental release of 6,000 cfs had substantial effects on water temperatures at Weitchpec (Figure 5.49). Average weekly water temperatures decreased from 70.2° to 59.8 °F for the week of June 3 to June 10. Extensive shading (both topographic and vegetative), the small increase of channel width relative to increased flows (stage–discharge relation), reduced travel time, and small accretions along the mainstem were probable reasons for reduced heat gain during this release (Zedonis, 1997).

Releases required to meet the temperature criteria presented in Table 5.11 can vary substantially depending on hydrometeorological conditions (Table 5.16). For example, releases required to meet a target of 59 °F would range from 150 cfs for cold-wet conditions, 2,600 cfs for median conditions, and 3,000 cfs for hot-dry conditions.

"... increased releases generally result in an increase in the number of river miles within or near the species' preferred rearing water-temperature range."

Longitudinal profiles show that increased releases tend to stabilize the thermal regime of the river regardless of meteorological conditions or season. For example, a 6,000-cfs dam release, when compared with a 150 cfs release, results in less variable water temperatures throughout the river during the weeks of April 1 (Figure 5.53) and July 1 (Figure 5.54). Less variable temperature regimes associated with increased releases generally result in an increase in the number of river miles within or near the species' preferred rearing water-temperature range (see Figures 5.53 and 5.54); this is particularly noticeable during early summer.

The magnitude of releases, release water temperatures, and meteorological conditions also have an influence on downstream water temperatures during the summer and fall, such as at Douglas City (Table 5.17). Simulations using a minimum release-water temperature (47° to 50° F), indicate that the CRWQCB-NCR objective of 60° F is met

Table 5.15. Categorization of year types from 1975 through 1994 and years for which the BETTER model results were available and applied.

Water Year Class	BETTER Modeled Year	Years that the BETTER Release Water Temperatures were Applied
Extremely Wet	1983	1978, 1982, 1983
Wet	1986	1975, 1980, 1984, 1986, 1993
Normal	1989	1989
Dry	1990	1976, 1979, 1981, 1985, 1987, 1988, 1990, 1992
Critically Dry	1977	1977, 1991, 1994

with a release of approximately 150 cfs for cold-wet conditions and 300 cfs for median and hot-dry conditions. With a maximum dam release water temperature (51° to 56° F), releases that range from 150 to over 600 cfs would be required to meet the objectives from cold-wet to hot-dry conditions. After September 15 when the temperature objective shifts to 56° F at Douglas City, releases less than 300 cfs would meet the objectives provided that release-water temperatures were near 47° F. Under hot-dry conditions and warmer releases (51.3° F), releases near 450 cfs meet the objective.

To meet the CRWQCB-NCR objective of 56° F at the confluence of the North Fork Trinity River using minimum release-water temperatures (46.6° F), a flow between 300 and 450 cfs would be required during hot-dry conditions, whereas a flow of 150 and 300 cfs would meet the objective during cold-wet and median year type conditions, respectively (Table 5.17). With maximum release-water temperatures (51.1° F), releases required to meet the objective would range from less than 150 cfs in cold-wet conditions to greater than 450 cfs during hot-dry conditions. After mid-October, air temperatures are generally cooler, and flows less than 150 cfs would be sufficient to meet the objective through December for hot-dry, median, and cold-wet hydrometeorological conditions.

Empirical data indicate that a release of 450 cfs generally meets the objectives (Table 5.18). For the years 1992 to 1994 and 1996 to 1997, average weekly releases ranged from 300 to 600 cfs, and releases near 450 cfs were most prevalent. During these 5 years, the temperature objectives were exceeded in only 5 weekly periods. Exceedence of the objectives occurred during three weekly periods in July of 1992 and 1993 when release-water temperatures were equal to or greater than 53° F and flows were near 450 cfs. In mid-September of 1993, the objective was exceeded when dam releases were near 50° F and flows were 300 cfs.

Assuming constant release-water temperatures, longitudinal profiles indicate that even a small augmentation of releases can increase the number of miles of river falling within or near the preferred temperature range for juvenile salmonids (Figure 5.55). For example, under hot-dry hydrometeorological conditions and a 50 cfs dam release, water temperatures would be below the 57.2° F upper preferred temperature for approximately 3 miles of river below Lewiston Dam. Under similar hydrometeorological conditions and a 450 cfs dam release, the number of

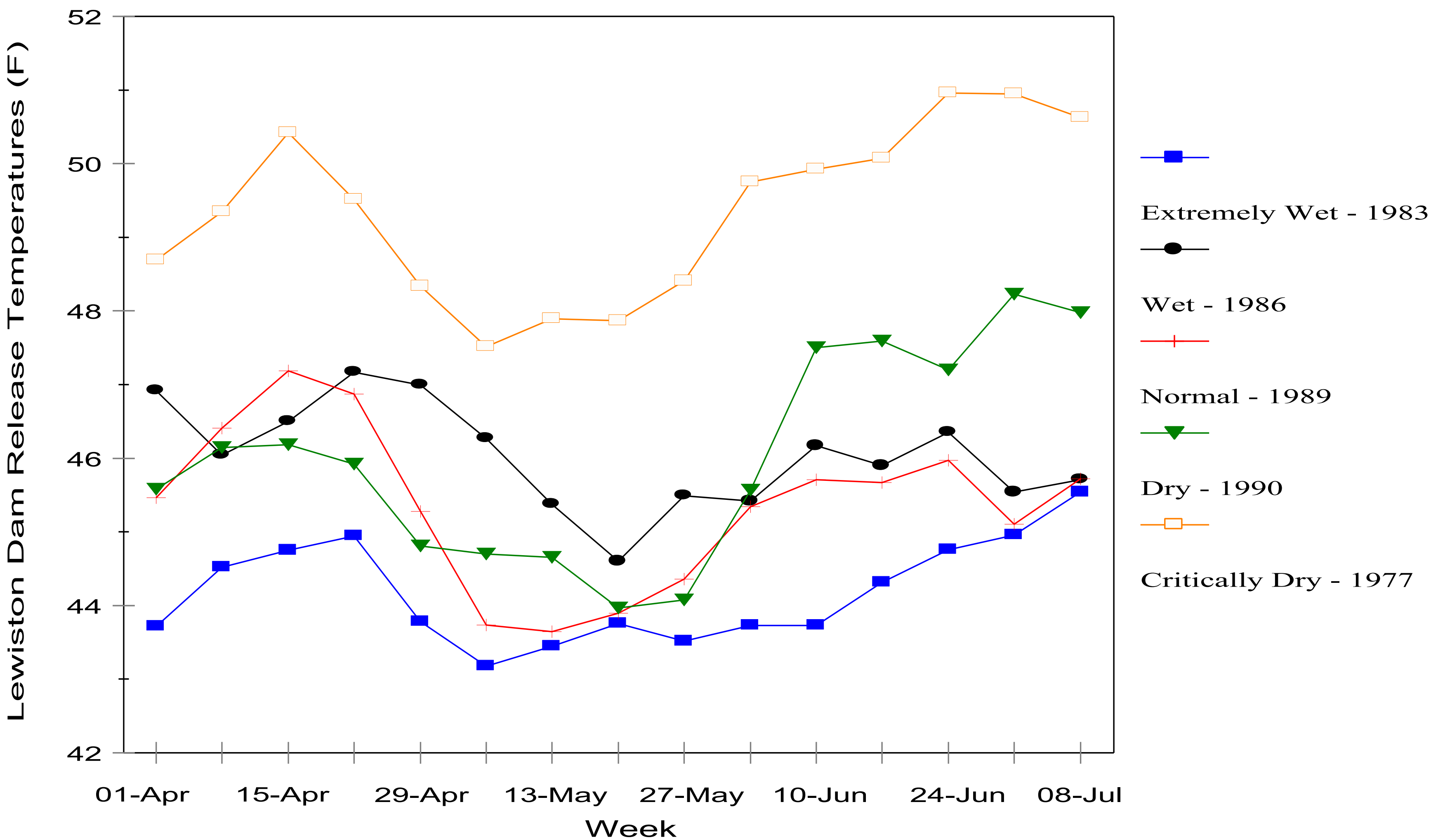


Figure 5.50. BETTER model predicted temperatures for five historic years, representing five water-year classes.

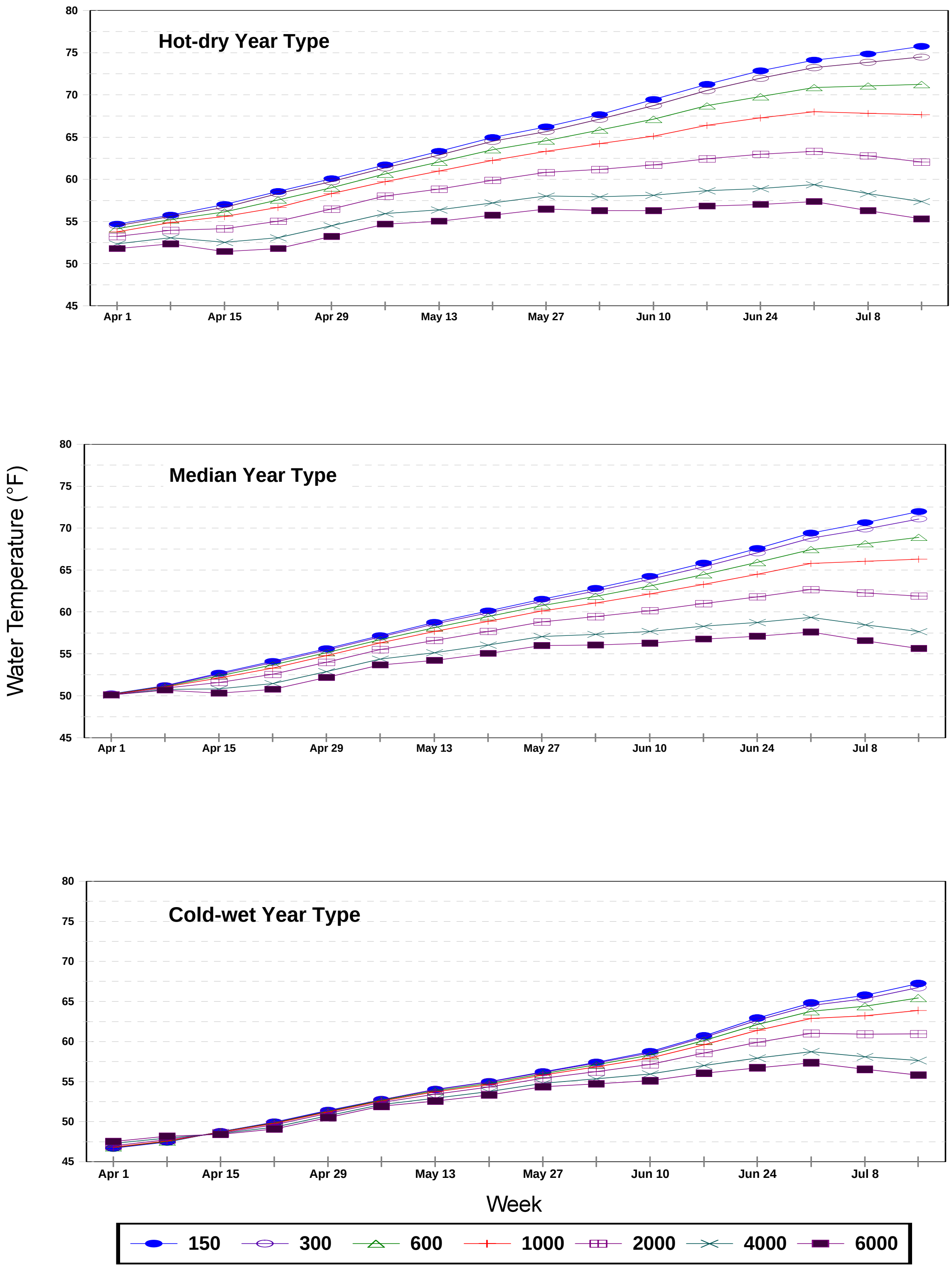


Figure 5.51. Stream Network Water Temperature Model (SNTEMP) temperature predictions (7-day average) for the Trinity River near Weitchpec (RM 5.3) with Lewiston Dam releases between 150 and 6,000 cfs and hot-dry (HD), median (Med), and cold-wet (CW) year type conditions. Release water temperatures used were 7-day average minimum water temperatures observed below Lewiston Dam from 1987 to 1994.

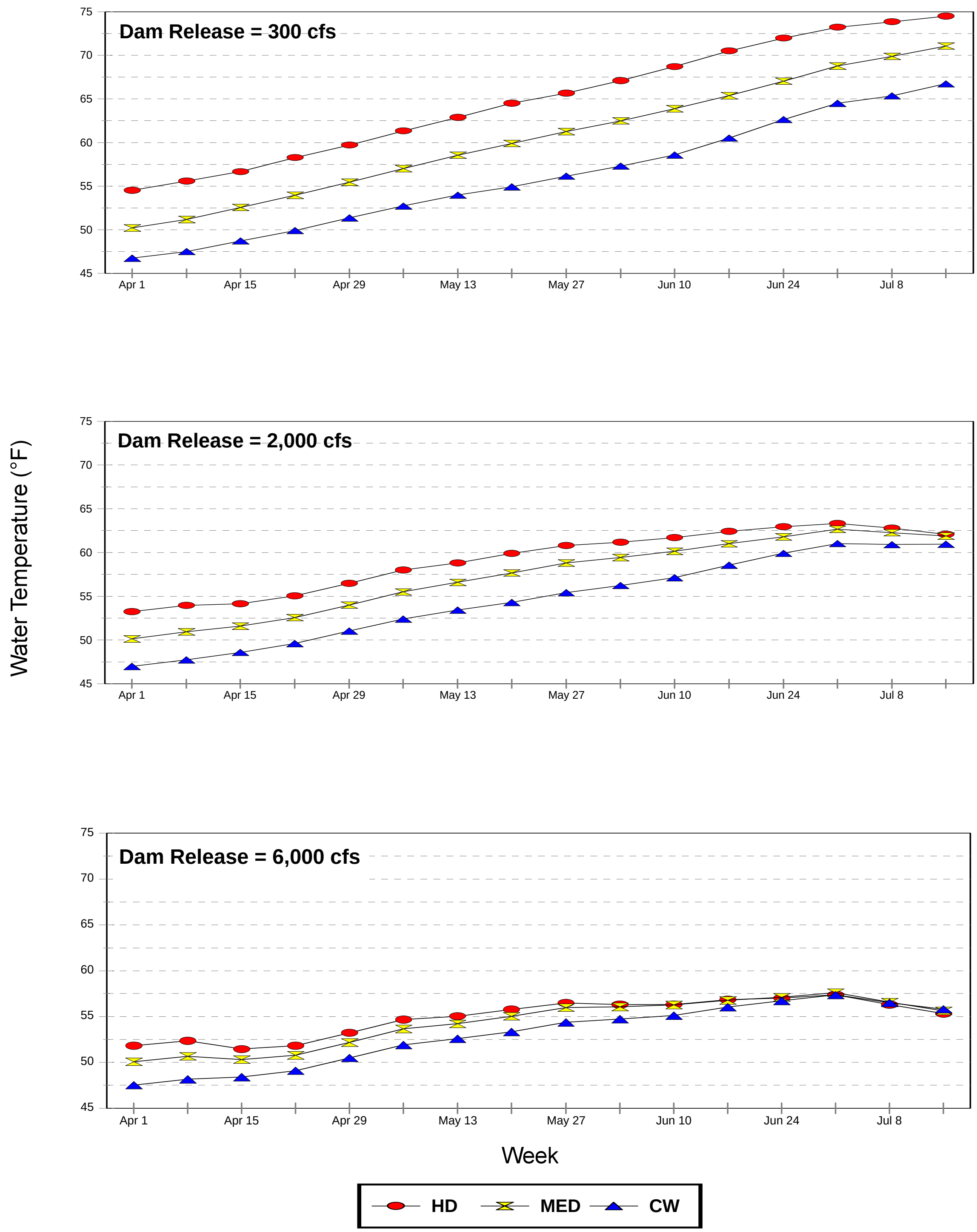


Figure 5.52. Comparison of SNTEMP model output for three different dam releases for hot-dry (HD), median (Med), and cold-wet (CW) hypothetical year conditions during the spring and early summer near Weitchpec (RM 5.3). Release water temperatures used were 7-day average minimum water temperatures observed below Lewiston Dam from 1987 to 1994.

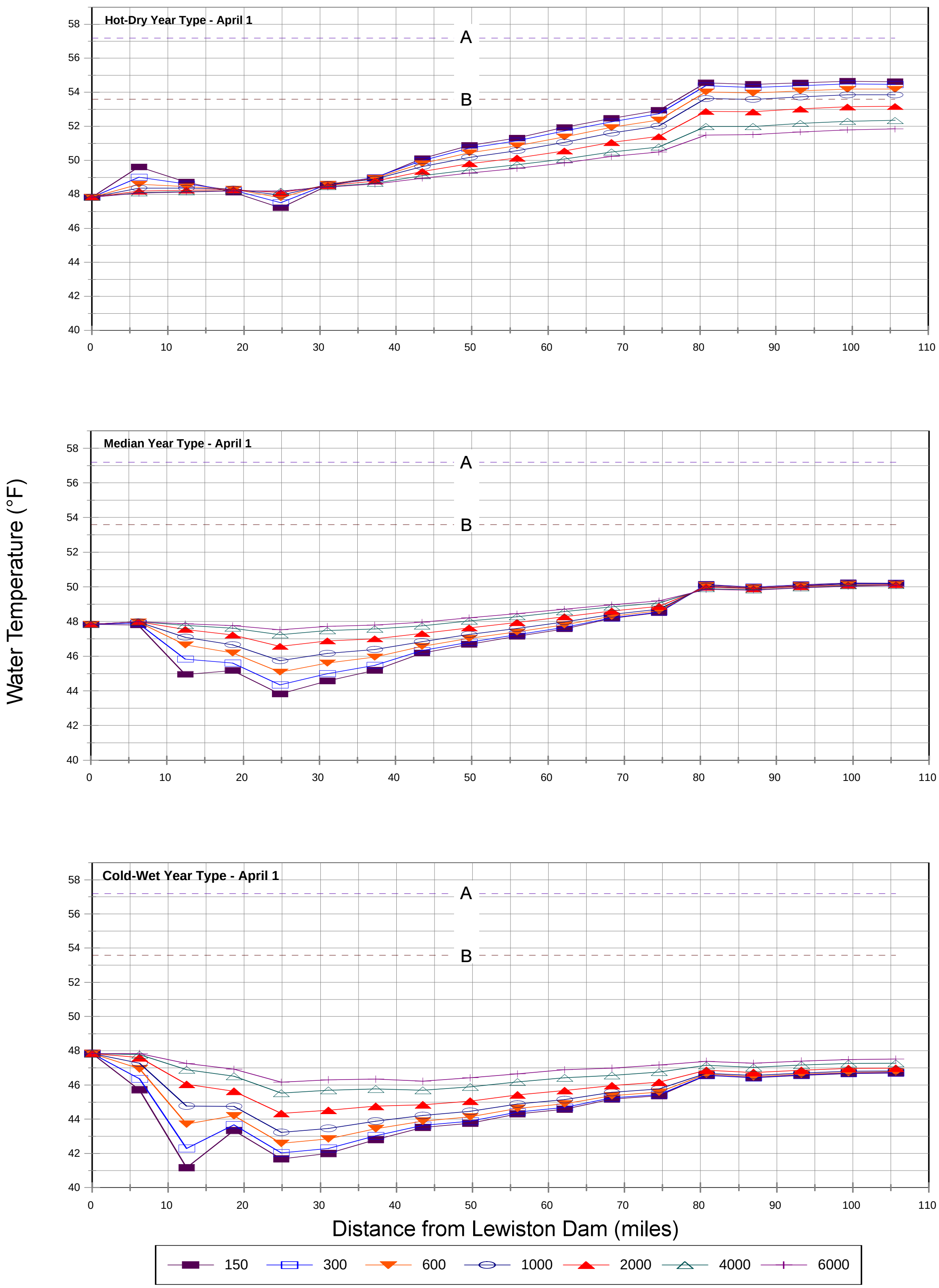


Figure 5.53. Longitudinal profiles of predicted water temperatures for April 1 with Lewiston Dam releases of 150 to 6,000 cfs and hot-dry, median, and cold-wet hydrometeorological conditions. Upper "A" and lower "B" preferred water temperatures of chinook and coho salmon juveniles. Temperature criteria are from Table 5.13.

Table 5.16. Approximate dam releases at Lewiston, under hot-dry, median, and cold-wet hydrometeorological conditions, to meet temperature targets during salmon and steelhead smolt outmigration through the lower Trinity River.

Smolt Species	Approx. Date of at least 80% Emigration at the Willow Creek Trap Site	Optimal Temperature Conditions				Marginal Temperature Conditions			
		Water Temperature Target (°F)	Approximate Dam Release Magnitude (cfs) to Meet the Target			Water Temperature Target (°F)	Approximate Dam Release Magnitude (cfs) to Meet the Target		
			Year Type				Year Type		
			Hot-dry	Median	Cold-wet		Hot-dry	Median	Cold-wet
Steelhead	May 22	< 55.4	> 6,000	6,000	< 150	< 59	2,500	1,200	< 150
Coho Salmon	June 4	< 59	3,000	2,600	< 150	< 62.6	1,500	300	< 150
Chinook Salmon	July 9	< 62.6	2,000	1,900	1,200	< 68	800	700	< 150

miles increases to about 18; under median and cold-wet hydrometeorological conditions the number of miles within the preferred water-temperature range increases.

5.5.3.2 Historical-Years Simulation Results and Alternative Release Patterns

Simulations using historical hydrometeorological conditions and BETTER-modeled simulated release-water temperatures allow prediction of river-water temperatures that would have resulted from different release schedules. Through an iterative process, release magnitudes can be identified that could have been used to meet temperature criteria at Weitchpec in historical years (Figure 5.56). Simulations for a wet year (1984) show that releases as small as 150 cfs would have met the temperature criteria in early April, but that releases near 4,000 cfs would have been needed to meet temperature targets in late May. Toward the end of the chinook salmon smolt emigration period, a release near 2,000 cfs would meet the optimal criteria.

Simulation results also show the variability of releases required to meet temperature criteria as a function of meteorology. On May 27, releases between 2,000 and 4,000 cfs would have been required to meet optimal criteria, whereas only a week later (June 3) a release of approximately 1,000 cfs would have met the same temperature criteria because of cooler meteorology.

Not surprisingly, longitudinal profiles of historical year simulations exhibit the same relation as that of the hypothetical-year type simulations, and therefore results are not presented. During early April, release magnitude does not have a significant influence on thermal habitat, but as summer approaches, increased releases can increase the amount of habitat falling within preferred temperature range of rearing juvenile salmonids (See Figures 5.53 and 5.54).

5.5.4 Conclusions

The SNTEMP model of the Trinity River is useful for predicting system thermal behavior under a variety of operations scenarios. The model illustrates the dynamic relation between meteorology, tributary

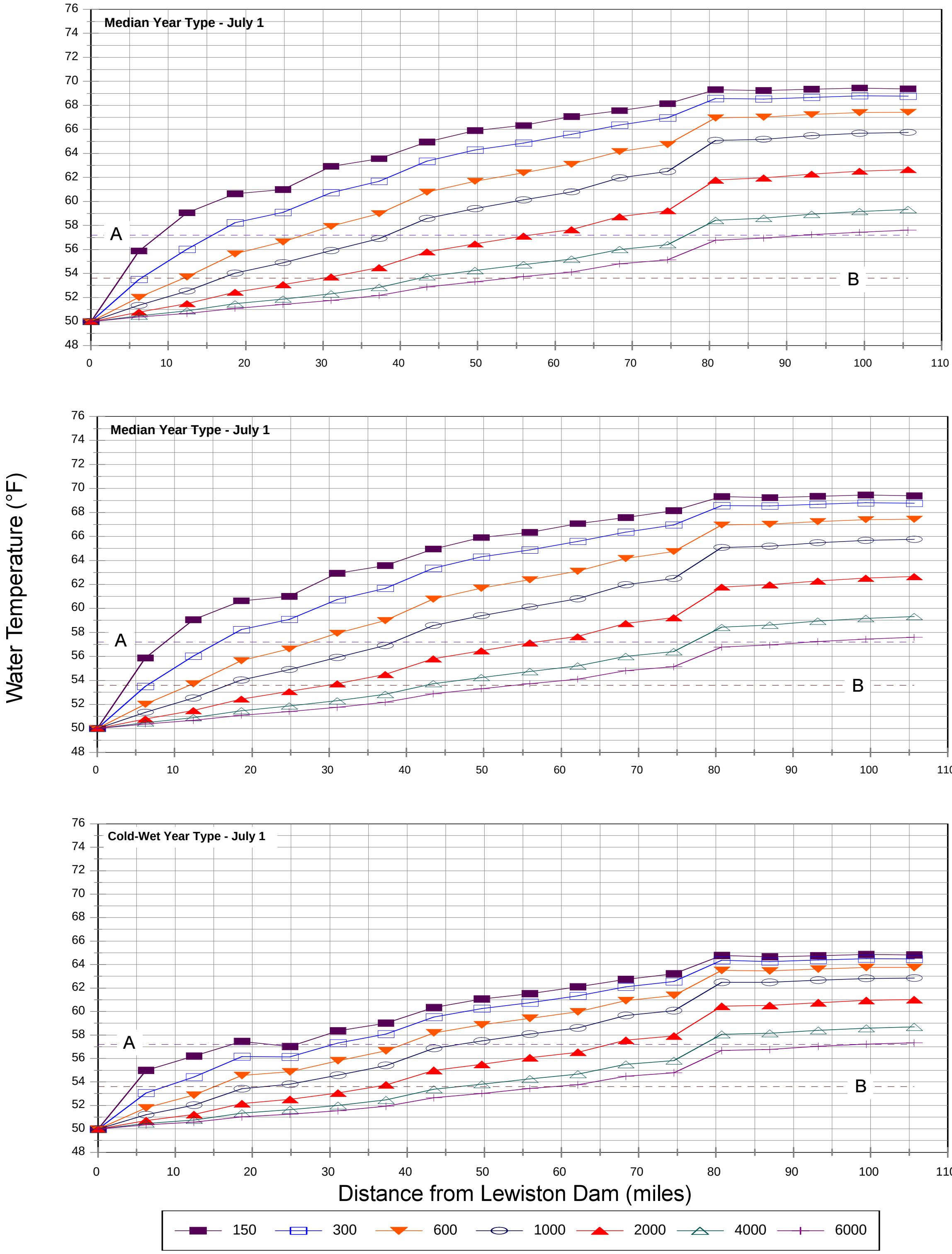


Figure 5.54. Longitudinal profiles of predicted water temperatures for July 1 with Lewiston Dam releases of 150 to 6,000 cfs and hot-dry, median, and cold-wet hydrometeorological conditions. Upper "A" and lower "B" preferred water temperatures of chinook and coho salmon juveniles. Temperature criteria are from Table 5.13.

Table 5.17. Stream Network Water Temperature Model (SNTEMP) temperature predictions (7-day average) for the Trinity River at CRWQCB-NCR Objective locations - Douglas City (RM 93.8) and the confluence of the North Fork Trinity River (RM 72.4). Bolded values indicate the temperature would not be met. CW = cold water year; MED = median year; HD = hot dry year.

WaterTemperaturePredictions(°F)																	
	Dam		LewistonDamReleases(cfs)														
	Release	Target	150			300			450			600			1000		
Week	Temp	Temp	CW	Med	HD	CW	Med	HD	CW	Med	HD	CW	Med	HD	CW	Med	HD
DouglasCity-MinimumReleaseWaterTemperatures																	
01-Jul	50.0	60	57.1	**60.2**	**63.9**	55.7	57.7	59.6	54.9	56.3	57.4	54.1	55.2	56.1	53.1	53.7	54.1
08-Jul	48.7	60	57.6	**60.8**	**64.0**	55.6	57.6	59.2	54.4	55.7	56.7	53.6	54.5	55.2	52.3	52.8	53.1
15-Jul	47.7	60	58.2	**61.5**	**64.2**	55.7	57.5	58.8	54.1	55.3	56.0	53.2	53.9	54.5	51.6	52.0	52.2
22-Jul	47.3	60	58.6	**61.9**	**64.2**	55.8	57.5	58.6	54.0	55.1	55.7	53.0	53.7	54.1	51.3	51.7	51.8
29-Jul	48.6	60	59.0	**62.6**	**64.9**	56.3	58.2	59.4	54.7	56.0	56.6	53.7	54.6	55.0	52.2	52.7	52.9
05-Aug	47.7	60	58.8	**62.1**	**64.0**	55.7	57.4	58.3	53.9	55.0	55.6	52.9	53.7	54.1	51.3	51.7	52.0
12-Aug	46.9	60	58.2	**61.3**	**63.1**	54.9	56.5	57.4	53.0	54.1	54.7	52.0	52.8	53.2	50.5	50.9	51.1
19-Aug	47.1	60	57.6	**60.6**	**62.1**	54.4	56.1	56.8	52.7	53.8	54.3	51.8	52.6	52.9	50.3	50.8	50.9
26-Aug	47.1	60	56.5	59.7	**61.0**	53.6	55.4	55.9	52.0	53.3	53.7	51.2	52.2	52.4	49.9	50.5	50.7
02-Sep	47.1	60	55.3	58.4	59.9	52.8	54.6	55.4	51.4	52.7	53.2	50.7	51.7	52.0	49.6	50.2	50.4
09-Sep	47.1	60	54.0	57.5	58.8	51.9	54.0	54.5	50.7	52.3	52.6	50.1	51.3	51.6	49.2	49.9	50.2
16-Sep	46.9	56	52.7	**56.4**	**57.6**	51.0	53.2	53.8	50.0	51.6	52.0	49.5	50.7	51.1	48.7	49.5	49.6
23-Sep	46.9	56	51.2	55.1	**56.3**	49.9	52.3	52.9	49.2	51.0	51.4	48.9	50.2	50.5	48.3	49.2	49.3
DouglasCity-MaximumReleaseWaterTemperature																	
01-Jul	56.1	60	58.5	**62.0**	**66.0**	58.1	**60.6**	**63.1**	58.0	**60.2**	**61.7**	57.7	59.2	**60.6**	57.4	58.4	59.2
08-Jul	55.6	60	59.2	**62.9**	**66.4**	58.5	**61.0**	**63.1**	58.4	**60.2**	**61.5**	57.8	59.2	**60.3**	57.2	58.2	58.8
15-Jul	52.9	60	59.6	**63.2**	**66.2**	58.1	**60.3**	**61.9**	57.4	58.8	59.8	56.5	57.7	58.5	55.5	56.2	56.7
22-Jul	52.7	60	**60.1**	**63.8**	**66.4**	58.4	**60.5**	**61.9**	57.5	58.9	59.6	56.6	57.7	58.3	55.5	56.1	56.5
29-Jul	52.7	60	**60.3**	**64.1**	**66.6**	58.4	**60.6**	**61.9**	57.4	58.9	59.6	56.5	57.7	58.3	55.4	56.1	56.5
05-Aug	52.0	60	**60.1**	**63.6**	**65.8**	57.9	60.0	**61.0**	56.8	58.1	58.8	55.9	56.9	57.4	54.7	55.4	55.6
12-Aug	53.1	60	**60.2**	**63.6**	**65.7**	58.2	**60.2**	**61.3**	57.2	58.5	59.2	56.4	57.5	58.3	55.4	56.1	56.5
19-Aug	52.3	60	59.3	**62.6**	**64.2**	57.3	59.3	**60.1**	56.3	57.6	58.2	55.6	56.6	57.0	54.6	55.2	55.6
26-Aug	51.6	60	58.1	**61.5**	**62.8**	56.2	58.2	59.0	55.2	56.6	57.1	54.5	55.7	55.9	53.7	54.4	54.5
02-Sep	51.4	60	56.9	**60.2**	**61.7**	55.3	57.3	58.1	54.5	55.9	56.4	53.9	55.0	55.4	53.2	53.9	54.1
09-Sep	52.9	60	56.0	59.9	**61.2**	55.2	57.6	58.3	54.8	56.5	56.9	54.4	55.8	56.1	54.0	54.9	55.0
16-Sep	51.1	56	54.2	58.1	**59.4**	53.3	55.8	**56.5**	52.9	54.7	55.1	52.6	54.0	54.3	52.2	53.1	53.2
23-Sep	51.3	56	52.7	56.5	**58.1**	52.4	55.0	55.8	52.3	54.2	54.6	52.1	53.6	54.0	51.9	52.9	53.1
NorthForkTrinityConfluence-MinimumReleaseWaterTemperatures																	
01-Oct	46.6	56	51.2	**57.0**	**59.2**	50.6	54.9	**56.3**	49.8	53.2	54.2	49.8	52.5	53.3	49.2	51.1	51.6
08-Oct	46.6	56	49.1	54.7	**57.4**	48.8	53.0	54.8	48.5	51.8	53.2	48.4	51.1	52.2	48.1	49.9	50.6
15-Oct	45.9	56	47.3	52.2	55.0	47.2	50.9	52.8	47.0	50.1	51.5	47.0	49.5	50.6	46.9	48.6	49.3
22-Oct	46.4	56	45.4	50.0	52.3	45.6	49.4	51.0	45.7	48.9	50.1	45.9	48.6	49.6	46.2	48.2	48.8
29-Oct	46.2	56	43.5	47.5	50.3	43.7	47.4	49.4	44.0	47.3	48.9	44.2	47.2	48.5	44.7	47.1	48.0
05-Nov	46.2	56	42.3	45.6	48.3	42.6	45.8	47.9	42.9	46.0	47.7	43.1	46.1	47.5	43.7	46.3	47.3
12-Nov	45.5	56	41.1	43.6	45.8	41.4	44.0	45.9	41.6	44.4	45.9	41.9	44.6	45.9	42.5	45.0	46.0
19-Nov	43.3	56	40.0	41.8	44.0	40.2	42.1	44.0	40.4	42.4	44.0	40.6	42.6	44.0	41.0	43.0	44.0
26-Nov	42.6	56	39.2	40.5	42.7	39.4	40.9	42.8	39.5	41.2	42.9	39.8	41.5	43.0	40.1	41.9	43.0
03-Dec	43.2	56	38.9	39.8	41.9	39.1	40.4	42.3	39.2	40.8	42.6	39.5	41.2	42.8	39.9	41.8	43.1
10-Dec	43.5	56	38.5	39.3	41.3	38.8	39.9	41.9	38.9	40.5	42.4	39.2	40.9	42.6	39.7	41.7	43.1
17-Dec	42.6	56	38.3	38.7	41.1	38.5	39.3	41.6	38.6	39.8	41.9	38.9	40.2	42.1	39.3	40.9	42.4
24-Dec	40.6	56	38.3	38.4	40.5	38.4	38.8	40.6	38.4	39.0	40.7	38.6	39.3	40.8	38.8	39.7	41.0
NorthForkTrinityConfluence-MaximumReleaseWaterTemperatures																	
01-Oct	51.1	56	51.7	**57.6**	**59.8**	51.7	**56.3**	**57.8**	51.7	55.3	**56.5**	51.7	54.8	55.7	51.7	53.8	54.4
08-Oct	51.1	56	49.7	55.4	**58.1**	50.0	54.6	**56.5**	50.3	54.0	55.5	50.5	53.7	54.9	50.8	53.1	53.9
15-Oct	50.5	56	47.9	53.0	55.8	48.4	52.6	54.6	48.8	52.3	53.9	49.1	52.1	53.4	49.6	51.8	52.7
22-Oct	50.0	56	45.8	50.6	52.9	46.4	50.6	52.3	46.9	50.6	52.0	47.3	50.6	51.8	48.1	50.6	51.4
29-Oct	49.8	56	43.7	48.0	50.9	44.3	48.6	50.8	44.8	48.9	50.7	45.2	49.1	50.7	46.2	49.5	50.6
05-Nov	52.0	56	42.7	46.4	49.3	43.3	47.6	50.1	44.0	48.5	50.6	44.6	49.1	50.9	45.9	50.1	51.4
12-Nov	53.1	56	41.5	44.6	47.2	42.2	46.4	48.8	42.9	47.5	49.7	43.6	48.5	50.5	45.1	49.9	51.4
19-Nov	52.3	56	40.4	42.9	45.6	41.1	44.7	47.5	41.7	45.9	48.5	42.4	47.0	49.3	43.7	48.6	50.4
26-Nov	51.1	56	39.6	41.5	44.2	40.2	43.2	46.0	40.7	44.4	47.1	41.3	45.4	47.9	42.5	47.1	49.1
03-Dec	48.9	56	39.1	40.5	42.9	39.6	41.8	44.5	40.0	42.9	45.4	40.4	43.8	46.2	41.5	45.2	47.2
10-Dec	47.5	56	38.7	39.7	42.0	39.1	40.9	43.4	39.5	41.8	44.3	39.8	42.6	45.0	40.7	44.0	45.9
17-Dec	46.0	56	38.4	39.1	41.7	38.8	40.1	42.8	39.1	40.9	43.5	39.4	41.7	44.1	40.2	42.9	44.8
24-Dec	45.3	56	38.4	38.9	41.3	38.7	39.8	42.3	39.0	40.5	42.9	39.3	41.1	43.4	40.0	42.3	44.2

Table 5.18. Average weekly dam release temperatures and volumes from 1992 to 1994 and 1996 to 1997 in relation to meeting the CRWQCB-NCR water objectives established in 1991. Objectives (target temperatures) are 60° F at Douglas City for July 1 to Sept 14; 56° F at Douglas City from Sept 15 to Sept 30; and 56° F at the confluence of the North Fork Trinity River for Oct 1 to Dec 31. Bolded values indicate the target objective was exceeded. na = not available.

	1992				1993				1994			
	Dam Release		Water Temp. (F)	Target	Dam Release		Water Temp. (F)	Target	Dam Release		Water Temp. (F)	Target
Week	Temp (F)	Flow (cfs)	at the Target Location	Temp (F)	Temp (F)	Flow (cfs)	at the Target Location	Temp (F)	Temp (F)	Flow (cfs)	at the Target Location	Temp (F)
01-Jul	na	317	59.7	60	**55.7**	**436**	**61.6**	**60**	49.7	468	57.0	60
08-Jul	**53.0**	**317**	**62.7**	**60**	**55.6**	**447**	**61.3**	**60**	50.0	483	57.0	60
15-Jul	**53.4**	**421**	**61.1**	**60**	55.6	460	58.9	60	49.9	466	57.5	60
22-Jul	na	467	59.9	60	51.7	467	58.8	60	50.2	470	56.9	60
29-Jul	52.6	438	59.6	60	53.2	458	59.4	60	49.6	469	56.4	60
05-Aug	51.1	435	59.0	60	51.5	489	57.4	60	50.0	469	56.1	60
12-Aug	53.3	511	59.8	60	51.8	470	57.3	60	49.7	469	55.8	60
19-Aug	52.7	520	57.2	60	51.0	447	57.0	60	50.2	479	55.4	60
26-Aug	51.3	520	56.6	60	51.9	451	56.4	60	50.2	445	55.2	60
02-Sep	51.9	533	55.6	60	50.6	600	55.0	60	50.2	447	55.6	60
09-Sep	51.3	532	55.1	60	49.3	457	53.9	60	na	443	55.7	60
16-Sep	51.0	531	54.8	56	50.5	459	52.9	56	51.6	441	55.0	56
23-Sep	51.2	530	54.6	56	49.1	381	52.1	56	50.4	435	54.1	56
01-Oct	50.6	532	54.6	56	**49.9**	**309**	**56.6**	**56**	na	na	na	56
08-Oct	50.1	467	54.3	56	49.5	299	55.0	56	na	na	na	56
15-Oct	49.6	390	53.1	56	48.8	311	54.2	56	na	na	na	56

	1996				1997			
	Dam Release		Water Temp. (F)	Target	Dam Release		Water Temp. (F)	Target
Week	Temp (F)	Flow (cfs)	at the Target Location	Temp (F)	Temp (F)	Flow (cfs)	at the Target Location	Temp (F)
01-Jul	49.0	500	58.0	60	48.6	484	56.6	60
08-Jul	49.0	480	59.2	60	na	498	57.4	60
15-Jul	47.8	488	57.6	60	na	489	57.5	60
22-Jul	49.4	490	57.7	60	na	487	57.9	60
29-Jul	50.1	485	57.9	60	50.8	491	56.7	60
05-Aug	50.2	491	57.4	60	51.6	487	57.7	60
12-Aug	49.8	489	56.7	60	51.8	483	57.6	60
19-Aug	49.6	486	55.9	60	51.5	487	57.0	60
26-Aug	49.6	483	55.3	60	51.3	599	55.9	60
02-Sep	49.5	471	53.8	60	51.3	492	55.8	60
09-Sep	49.7	440	54.0	60	50.7	454	55.0	60
16-Sep	49.9	440	53.1	56	51.2	461	54.4	56
23-Sep	49.8	448	53.0	56	51.8	462	54.6	56
01-Oct	49.5	463	55.8	56	51.5	na	na	56
08-Oct	49.5	475	54.5	56	49.7	na	na	56
15-Oct	49.3	361	51.1	56	49.5	na	na	56

Note: empirical data presented here may not match model output data from Table 5.17 because hydrometeorological input data may differ.

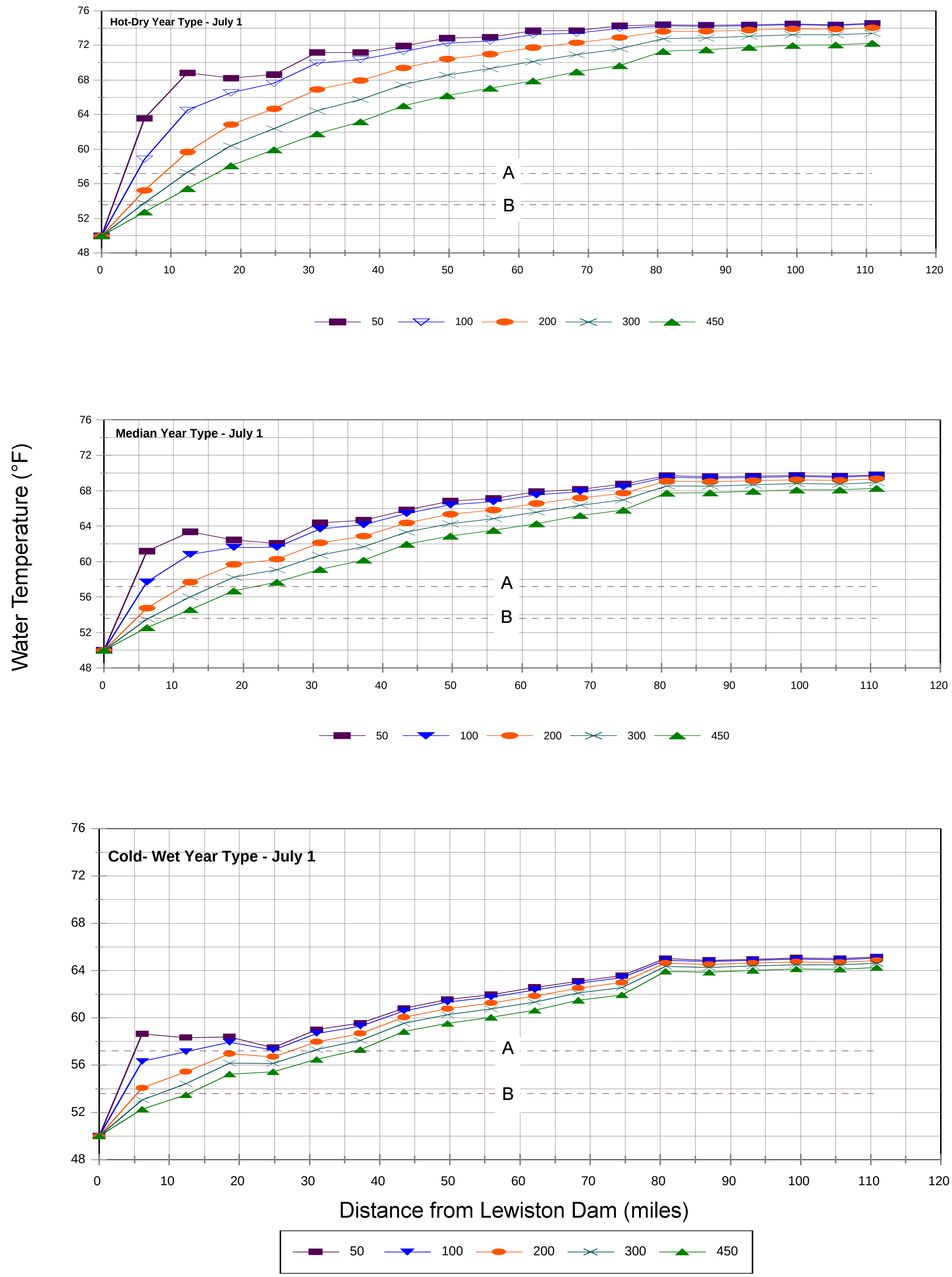


Figure 5.55. Longitudinal profiles of predicted water temperatures for July 1 with Lewiston Dam releases from 50 to 450 cfs and hot-dry, median, and cold-wet hydrometeorological conditions. Upper "A" and lower "B" preferred water temperatures of chinook and coho salmon juveniles. Temperature criteria are from Table 5.13.

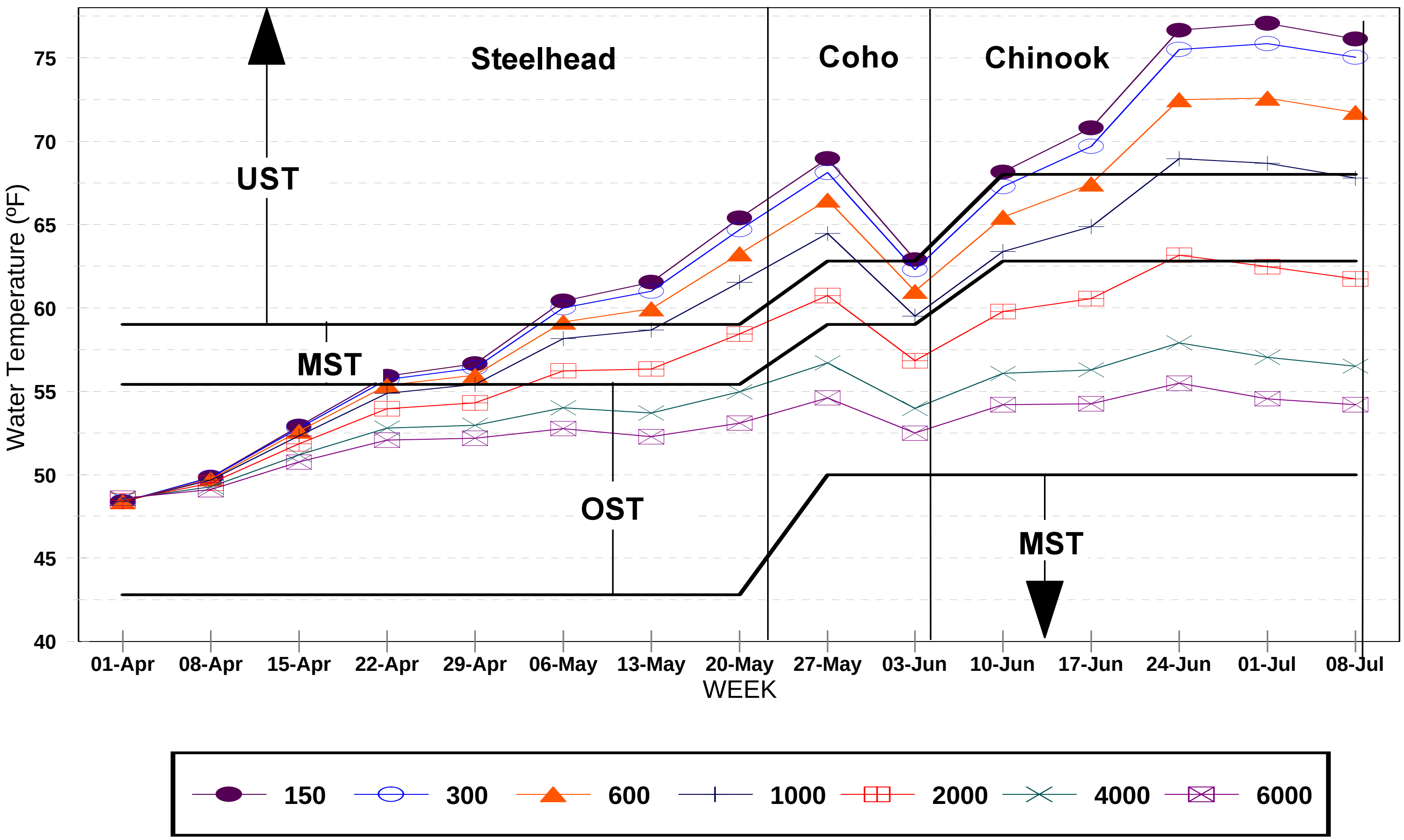


Figure 5.56. Predicted water temperatures for a historic WET year (1984) at Weitchpec (RM 0.0) with Lewiston Dam releases ranging from 150 to 6,000 cfs. Results are based on constant release temperatures. UST = unsuitable smolt temperatures, MST = marginal smolt temperatures, and OST = optimal smolt temperatures.

dynamic relation between meteorology, tributary hydrology, dam release temperatures, and release magnitudes that influence downstream water temperatures.

Hypothetical- and historical-year type simulations both provided valuable information on how the Trinity River system is likely to behave under a variety of scenarios. Hypothetical-year type simulations showed sensitivity of downstream water temperatures over varied releases and a broad set of hydrometeorological conditions. Unlike hypothetical-year types, use of historical years allowed prediction of releases that would have been needed to meet spring water-temperature criteria. Use of historical years provides a necessary link to basin hydrology (i.e., water-year classes) and therefore should be used in development of final recommendations for spring temperature objectives.

"Increasing dam releases during the spring and early summer can improve or restore temperature conditions in the river that promote better growing conditions and smolt survival."

Simulations and empirical data show that water temperatures throughout the Trinity River are influenced by dam releases during the spring. Additionally, an examination of water temperatures before and after the construction of the TRD show that spring and early summer water temperatures have become warmer throughout the Trinity River as a result of storage/diversion of snowmelt runoff from the watershed above Trinity Dam (see Section 4.3.6). Increasing dam releases during the spring and early summer can improve or restore temperature conditions in the river that promote better growing conditions and smolt survival. Furthermore, increased dam releases and associated increased water velocities should decrease emigration time to the Pacific Ocean, and therefore increase the survival rates of smolts.

Additional benefits of increased magnitude and duration of spring releases would include: (1) improved water temperatures for migrating spring-run chinook salmon and summer steelhead adults and for outmigrating run-back adult steelhead in the Trinity and Klamath Rivers; (2) improved water-temperature and water-quality (dissolved oxygen) regimes within the Trinity and Klamath Rivers for life stages that rear or hold during the summer; and (3) improved flow conditions in the Trinity and Klamath Rivers for hatchery-produced salmonids.

Because spring- and fall-run chinook salmon require cold water to survive and successfully spawn, but can no longer access cold-water areas above Lewiston Dam, there is a need to artificially maintain a cold-water segment below Lewiston Dam. CRWQCB-NCR water- temperature objectives (Table 5.12) would provide necessary thermal refugia for adult salmon and steelhead. To meet these objectives, it is recommended that flows of 450 cfs be maintained during the summer and early fall. Although this flow can be high for this time of the year in comparison with pre-TRD flows, it is needed to ensure maintenance of suitable water temperatures for adult salmon and steelhead. Empirical data from 1992 to 1997 (Table 5.18) show that releases near 450 cfs met the temperature targets under conditions of extremely warm air temperatures. Only when release-water temperatures were above approximately 53° F (during the early summer) were the temperature targets not met with a release of 450 cfs.

Simulations showed the influence of variables on water temperature under conditions not portrayed by empirical data. Simulations suggest that dam releases that range from 150 to 600 cfs would be required to meet the temperature targets, depending on hydrometeorology and release-water temperatures. Similar to what is shown by empirical data, model results indicate that a 450 cfs release would generally meet the

"CRWQCB-NCR water-temperature objectives would provide necessary thermal refugia for adult salmon and steelhead."

objectives under hot-dry conditions and when release-water temperatures are colder than approximately 53° F during early summer.

Additional evidence in support of maintaining 450-cfs releases during the summer and early fall is provided from spawning surveys (CDFG, 1996a, 1996b). Surveys conducted by the CDFG from 1992 to 1996 have shown a more even longitudinal distribution of spawning between Lewiston Dam and the confluence of the North Fork Trinity River (CDFG, 1996a, 1996b) with Lewiston Dam releases of 450 cfs, as opposed to 300 cfs. A wider distribution of spawners was likely a result of acceptable water temperatures extending farther downstream during the time when fish begin selecting spawning sites. Spreading spawners throughout more habitat could lessen the likelihood that fish would spawn on previously constructed redds. Another benefit of maintaining 450-cfs releases during the summer and early fall is that it provides several more miles of river below Lewiston Dam that fall within or near the preferred temperature range for juvenile salmonids.

5.6 Chinook Salmon Potential Production

5.6.1 Introduction

A potential production model, SALMOD, was developed for naturally produced young-of-year chinook salmon in the Trinity River reach from Lewiston Dam downstream 25 miles. The model evolved through a planned process of: (1) developing a conceptual model of the factors that significantly and directly affect spring-run and fall-run chinook salmon potential production; (2) specifying the important functional relations in mathematical models and combining them into a computer model; (3) verifying that the combined calculations were reasonable; (4) calibrating model output to available data for the period 1989 to 1991 and assembling additional data appropriate for the Trinity River study area; and

(5) validating the model by a means of a prediction–monitoring–improvement annual sequence in 1992 and 1993 (Williamson et al., 1993). Model validation was defined as making predictive estimates (in two workshops each year in late January and late March) of chinook salmon production for various proposed flow regimes and then gathering biological data from early March to early June to improve the model. Numbers of naturally produced coho salmon and steelhead were so low in the Trinity River at the time of the study that it was not considered cost effective to gather the biological data needed for calibration and validation for those two species. Consequently, SALMOD describes only chinook salmon in the Trinity River application.

SALMOD is a conceptual chinook salmon life-history model used for estimating the relative magnitude of potential production among alternative water management regimes (release magnitudes and temperatures) and habitat rehabilitation activities.

The conceptual model was developed using input from Trinity River fish experts (Williamson et al., 1993). The assembled experts believed that naturally produced chinook salmon potential production in the Trinity River was primarily controlled by: (1) physical habitat limitation effects on movement, mortality, and fish food production; (2) water- temperature-related effects on mortality and individual growth; and (3) seasonal-factor effects on movement and maturation. Specific assumptions included in the computer model are that young-of-year chinook salmon growth, maturation, movement, and mortality are directly related to physical space, hydraulic properties of habitat, and water temperature, which in turn are manageable by means of timing and amount of reservoir releases to the study area. According to the assembled experts, other potential effects were considered to be either insignificant or indirect for the Trinity River and were not represented in the mathematical and computer models. Because of lack of data, it was not considered feasible (although highly desirable) to attempt to build a complete life-history model that would include the highly variable effects on growth and mortality due to diseases, parasites, and predation in the study area and owing to water temperature, commercial harvest, sport fishing, and ocean conditions outside the study area.

Mesohabitat units in SALMOD correspond to mesohabitat mapping (Morhardt et al., 1983) and attendant habitat - flow mathematical relations measured by TRFE personnel. In SALMOD, the stream is represented by a set of mesohabitat units, each one having unique characteristics (habitat type and length) that define the quantity of habitat available at different flows and thus the "habitat capacity" of that mesohabitat unit to support a number of fry (<2 inches) and pre-smolt salmon (Williamson et al., 1993). In the model, mesohabitat units of the same habitat type produce the same amount of habitat per unit stream length at each of the various flows. The model tracks distinct weekly cohorts of fish that start as eggs deposited in a redd in a mesohabitat unit and subsequently mature and grow to sac fry and emergent fry as a function of water temperature. In SALMOD, larger fry and pre-smolts remain in the mesohabitat unit in which they emerged and smaller fry and pre-smolts are forced to move downstream if sufficient additional habitat is not available.

Modeled processes include: (1) egg deposition with redd superimposition (McNeil, 1967); (2) temperature-related egg maturation (Crisp, 1981) and young-of-year growth (Shelbourne et al., 1973); (3) season-induced movement (McDonald, 1960), freshet-induced movement (Godin, 1981) and habitat-induced movement (Chapman, 1962; Mesick, 1988); and (4) base mortality (TRFH estimates), movement-related mortality (hypothesized), and temperature-related mortality (USBOR, 1991). The model uses a weekly time step and mean weekly parameter values for a biological year defined as spawning/egg deposition (starting September 2) to mass pre-smolt exodus (ending June 9; around June 10 several million chinook salmon pre-smolts are released at the TRFH). Model output from SALMOD for the Trinity River estimated the weekly number and mean length of fry, pre-smolt, and immature smolt chinook salmon emigrating from the study area up to the time of the hatchery release. A detailed description of SALMOD's processes, input and output is given by Bartholow et al. (1999).

The study area, extending approximately 25 river miles from Lewiston Dam downstream to the confluence with Dutch Creek, was chosen as the most important young-of-year production portion of the Trinity River drainage (where most of the chinook salmon spawning redds occur). A maximum sustainable density of both fry and pre-smolts (separate habitat capacity for each) for a unit area of high-quality habitat in the Trinity River was estimated from field measurements of available habitat and the 90th percentile of observed fry and pre-smolt densities. Required parameters for which Trinity River data were not available were solicited from the local river-system experts, gathered from pertinent literature, or used as variables during calibration. The calibration process involved comparing observed to simulated values and adjusting model parameters to more closely match (1) timing of peak young-of-year abundance and (2) size and relative number of outmigrants through time. A comparison was made of observed and uncalibrated, simulated annual production estimates in Bartholow et al. (1993). There are several limitations to SALMOD as applied to the Trinity River:

1. Only measured channel form and hydraulics were incorporated into SALMOD because estimates of future channel form and hydraulics were not available. Future changes to channel morphology must be measured or estimated to provide model input necessary to generate new habitat versus flow relations (e.g., Figure 5.17).

2. At unmeasured flows, flow-habitat values were linearly interpolated between the values for the measured flows. The original study (1990 to 1994) was designed to evaluate flows in the range of 300 to 3,000 cfs within the existing riparian-bermed channel (Williamson et al., 1993). Hydraulic measurements and direct habitat estimates (without hydraulic modeling) for planned reservoir releases of 150, 350, 450, 800, 1,500, 2,000, and 3,000 cfs were made by TRFE personnel using habitat-suitability criteria from Hampton (1988). Later measurements at 24 percent of the transects during a short-duration 4,500-cfs planned reservoir release provided evidence that habitat values did not decrease at flows above 3,000 cfs (Figure 5.18). For this analysis, we assumed that habitat estimates for all flows above 3,000 cfs were virtually the same as that measured for 3,000 cfs.

3. Only the 25 miles from Lewiston Dam downstream to Dutch Creek were included in the initial application of SALMOD. All production estimates are based on simulations of young-of-year chinook salmon exiting this segment of the river and are not an estimate of the total production from the Trinity River.

4. Freshet-induced movement parameters relating to flow triggers, proportion moving, average distance moved, and mortality rates were poorly estimated. After several years of effort to better quantify these parameters, a decision was made by workshop participants in March 1993 to reduce to zero the movement effects of freshets on the basis of sampling data from screw traps (Glase, 1994a) and fyke nets (CDFG, 1992b, 1994a, 1995).

5. The effects of flow and physical habitat on fish food production were not incorporated in the models because of the high effort and likely poor resolution (i.e., inherent extremely high intra-annual variation) of a separate model of invertebrate production.

Subsequent evaluations using SALMOD have been reported for the effects of spatial scale and spawning (Bartholow, 1996), weekly flow regimes (Bartholow and Waddle, 1994, 1995), and reservoir storage (Waddle and Sandelin, 1994).

5.6.2 Methods

A stream network hydrologic analysis was used to estimate tributary accretions downstream from Lewiston Dam, with either known releases (historical data) or projected flow releases as the flow in the first river segment. The SNTEMP model calibrated to the Trinity River (Zedonis, 1997) used historical meteorology data for each of 17 years (1976 to 1992) to estimate changes in river-water temperature from initial reservoir release temperatures for 7 Trinity River segments from Lewiston Dam to Dutch Creek. Initial reservoir release temperatures came from several sources, including measured temperatures (for the historical data); projected temperatures from a linear regression that used Julian day of year and natural logarithm of flow as the independent variables (Bartholow and Waddle, 1995); and projected temperatures from the BETTER-Lewiston Reservoir model (Trinity County, 1992). The historical and regression-model temperatures were used to construct a 17-year historical sequence. The BETTER-Lewiston Reservoir model was used to construct a representative year for each of the five water-year classes and is described in Section 5.5.

Representative individual years were chosen for each of the five recommended water-year class flow regimes. The 369 TAF Critically Dry water year was represented by WY1977 (October 1, 1976, to September 30, 1977); the 453 TAF Dry water year, 647 TAF Normal water year, 701 TAF Wet water year, and 815 TAF Extremely Wet water year were represented by WY1990, WY1989, WY1986, and WY1983, respectively. These years were selected as representative of their respective total annual flow ranges for the historical record from 1976 to 1992. The values calculated for a particular year are intended to represent the potential production for a particular water-year class and associated meteorological-year class and assumed reservoir release temperatures. Using representative years does not allow examination of previous years' effects (e.g., from the prolonged drought of the late 1980's and early 1990's). However, each year's young-of-year salmon production is at least somewhat independent of the previous year's production (generally low autocorrelation between successive years was expected).

Returning adult chinook salmon estimates from CDFG's Klamath River "megatable" (CDFG, 1996c) gave the minimum (4,000), mean (33,000), and maximum (68,000) observed seeding values used. A few parameters in SALMOD (Bartholow et al., 1999) were updated from previously reported values to include an additional 3 years of Trinity River Restoration Program data collection. Weekly mean values from CDFG's carcass surveys for the period 1989 to 1995 were used to quantify the characteristics of returning spawners, including distribution by river zone, percent adult females, percent pre-spawn mortality, and total number (CDFG, 1992a, 1992b, 1994a, 1995, 1996a, 1996b).

SALMOD was initially used to compare the effects of various flow regimes (annual volumes with a mean weekly release and attending river-water temperatures) on young-of-year chinook salmon potential production within the present riparian-bermed channel along the 25 mile study area. The five flow schedules derived from the water volumes identified in the 1981 Secretarial Decision (described in Chapter 6) are referred to as: (1) 140 TAF constant flow schedule with 194 cfs release year round; (2) 220 TAF constant flow schedule with 305 cfs release year round; (3) 287 TAF spring-outmigration flow schedule; (4) 340 TAF sediment-transport flow schedule; and (5) 340 TAF spring-outmigration flow schedule. In addition, the flow regimes developed and presented in Chapter 8 for five water-year classes (369 TAF Critically Dry water year; 453 TAF Dry water year; 647 TAF Normal water year; 701 TAF Wet water year; and 815 TAF Extremely Wet water year) were compared.

Model runs examined the combined effects and sensitivity of potential production to changes in spawning, fry rearing, and pre-smolt rearing micro-habitats. This was done by doubling or halving spawning habitat (by doubling and halving required redd size), fry-rearing habitat (by doubling and halving fry habitat capacity), and pre-smolt rearing habitat (by doubling and halving pre-smolt habitat capacity). These model runs used the largest number of spawners (68,000), the best identified individual flow regime (the 647 TAF Normal water year), and regression-model water temperatures to simulate what could have been produced under the various conditions present during the 17-year period from 1976 to 1992. This gives an indication of what could perhaps be accomplished in the future by improved microhabitat conditions within a rehabilitated channel.

Flows and associated temperatures outside the range of dates September 2 through June 9 (when chinook salmon are present in the study area) do not affect SALMOD estimates of potential production. Variations in potential production owing to different reservoir release water temperatures and exactly the same reservoir discharges throughout the period September 2 to June 9 became a focal point. To search for a near-optimal water temperature for growth and survivorship, model runs used the instream flow regimes from the Trinity River Flow Evaluation with BETTER model reservoir release water temperatures for the representative water years, except that springtime reservoir release water temperatures were forced to 46°, 50°, 54°, 57° or 61° F for the period March 4 to June 17. To identify a nearly global maximum young-of-year production from the current Trinity River channel morphology, additional model runs were made that incorporated the mean and maximum observed number of spawners, the near-optimal water temperature for growth and survivorship and a doubling of spawning, fry rearing, and pre-smolt rearing habitat.

5.6.3 Results

5.6.3.1 Secretarial Decision Flow Schedules

The chinook salmon young-of-year potential production for the five Secretarial Decision flow schedules is presented in Table 5.19. Assuming that 4,000 adults return to spawn in the study area with the same Secretarial Decision flow schedule for all 17 years and regression-model water temperatures, potential production increased from 633,000 young-of-year outmigrants with historical (1976 to 1992) flows and river temperatures to 887,000 (+40 percent) for the 340 TAF spring outmigration flow schedule. Potential production also would increase for other Secretarial Decision flow schedules from the 140 TAF constant flow schedule (+9 percent), the 220 TAF constant flow schedule (+29 percent), the 287 TAF spring outmigration flow schedule (+36 percent), and the 340 TAF sediment-transport flow schedule (+34 percent). Assuming the lowest observed number of 4,000 spawners, potential production of naturally produced young-of-year chinook salmon was limited to less than 900,000 under all Secretarial Decision flow schedules.

> As the annual flow volumes increased, the coefficient of variation for potential production generally decreased, suggesting that increased flows may also lower the risk of poor production across years.

Assuming the mean level of 33,000 spawners with the same Secretarial Decision flow schedules for all 17 years and regression-model water temperatures, potential production increased from 1,901,000 outmigrants under historical flows and river temperatures to 2,360,000 (+24 percent) in the 220 TAF constant-flow schedule. Production also increased for the 140 TAF constant-flow schedule (+16 percent), the 287 TAF spring-outmigration flow schedule (+19 percent), the 340 TAF sediment-transport flow schedule (+13 percent), and the 340 TAF spring-outmigration flow schedule (+23 percent).

Assuming 68,000 spawners with the same Secretarial Decision flow for all 17 years and regression-model water temperatures, potential production increased from 2,217,000 under historical flows and river temperatures to 2,721,000 (+23 percent) for the 220 TAF constant-flow schedule. Production also increased for all flows from the 140 TAF constant-flow schedule (+18 percent), the 287 TAF spring-outmigration flow schedule (+18 percent), the 340 TAF sediment-transport flow schedule (+12 percent), to the 340 TAF spring-outmigration flow schedule (+21 percent).

With the exception of the combination of 4,000 spawners and the 340 TAF sediment-transport flow schedule, as the annual flow volume increased the coefficient of variation decreased, suggesting that increased flows may also lower the risk of poor production across years (Table 5.19). In comparison with the lowest (4,000) observed spawning escapement, 33,000 spawners increased potential production of natural young-of-year chinook salmon by 150 percent to a mean of 2.26 million, and 68,000 spawners increased potential production of natural young-of-year chinook salmon by an additional 16 percent to a mean of 2.62 million. These values represent the production potential within the confining riparian berms of the existing channel.

5.6.3.2 Water-Year Class Flow Regimes

The chinook salmon young-of-year potential production within the existing channel for the five water-year class flow regimes are presented in Table 5.20. Assuming that 4,000 adults return to spawn in the study area with the same projected water-year class flow regime for all 17 years

Table 5.19. Mean potential production of young-of-year (1,000's) chinook salmon from the mainstem Trinity River study area for instream flow schedules derived from the 1981 Secretarial Decision annual flow volumes.[a]

Spawning Escapement	Historical Flows and Temperatures	Secretarial Decision Flow Schedules				
		140[b]	220[c]	287[d]	340[e]	340[f]
4,000	633 0.440[g]	692 0.191[g]	818 0.174[g]	864 0.160[g]	850 0.163[g]	887 0.154[g]
33,000	1,901 0.454[g]	2,213 0.247[g]	2,360 0.228[g]	2,254 0.212[g]	2,151 0.199[g]	2,329 0.191[g]
68,000	2,217 0.463[g]	2,622 0.276[g]	2,721 0.252[g]	2,619 0.228[g]	2,471 0.218[g]	2,681 0.206[g]

[a] Secretarial Decision Flow Volumes: 140,000 af, 220,000 af, 287,000 af, 340,000 af.
[b] 140,000 af with constant flow and regression model reservoir temperatures.
[c] 220,000 af with constant flow and regression model reservoir temperatures.
[d] 287,000 af with spring outmigration flow and regression model reservoir temperatures.
[e] 340,000 af with sediment transport flow and regression model reservoir temperatures.
[f] 340,000 af with spring outmigration flow and regression model reservoir temperatures.
[g] C.V. = Coefficient of variation for Water Years 1976-1992.

and regression-model water temperatures, potential production increased from 633,000 under historical flows and river temperatures to 901,000 (+42 percent) for the 369 TAF Critically Dry water year, to 917,000 (+45 percent) for the 701 TAF Wet water year, and then decreased to 898,000 (+42 percent) for the Extremely Wet water year. As with the Secretarial Decision flows, the low number of spawners limited the study area's potential production of naturally produced young-of-year chinook salmon to a mean of less than 920,000 outmigrants across the various water-year classes.

Assuming 33,000 spawners in the study area with the same projected water-year class flow regimes for all 17 years and regression-model water temperatures, potential production increased from 1,901,000 for historical flows and river temperatures to 2,337,000 (+23 percent) for the 369 TAF Critically Dry water year, to 2,607,000 (+37 percent) for the 647 TAF Normal water year, and decreased to 2,430,000 (+28 percent) for the Extremely Wet water year. In comparison with a spawning escapement of 4,000 fish, 725 percent more spawners (33,000) increased potential production by a mean of 176 percent to 2.50 million across the various water-year classes. In comparison with Secretarial Decision flow schedules, potential production of naturally produced young-of-year chinook salmon increased from a mean of 2.26 million to 2.50 million (+11 percent).

Increasing to 68,000 the number of spawners in the study area with the same projected water-year class flow regime for all 17 years and regression model water temperatures, potential production increases from 2,217,000 for historical flows and river temperatures to 2,623,000 (+18 percent) for the 369 TAF Critically Dry water year, to 3,124,000 (+41 percent) for the 647 TAF Normal water year, and then decreasing to 2,814,000 (+27 percent) for the Extremely Wet water year. In comparison with a spawning escapement of 33,000 fish, 106 percent more spawners increases the potential

Table 5.20. Mean potential production of young-of-year (1,000's) chinook salmon from the mainstem Trinity River study area for recommended flow regimes (TAF) from the Trinity River Flow Evaluation.[a]

Spawning Escapement	Historical Flows and Temperatures	Water-Year Class				
		Critically Dry 369[b]	Dry 453[c]	Normal 647[d]	Wet 701[e]	Extremely Wet 815[f]
4,000	633 0.440[g]	901 0.115[g]	908 0.133[g]	914 0.136[g]	917 0.131[g]	898 0.130[g]
33,000	1,901 0.454[g]	2,337 0.103[g]	2,540 0.144[g]	2,607 0.151[g]	2,593 0.140[g]	2,430 0.129[g]
68,000	2,217 0.463[g]	2,623 0.119[g]	3,021 0.163[g]	3,124 0.168[g]	3,077 0.154[g]	2,814 0.140[g]

[a] Study Evaluation Flow Volumes: 369,000 af, 453,000 af, 647,000 af, 701,000 af, 815,000 af.
[b] 369,000 af critically dry year flows with regression model reservoir temperatures.
[c] 453,000 af dry year flows with regression model reservoir temperatures.
[d] 647,000 af normal year flows with regression model reservoir temperatures.
[e] 701,000 af wet year flows with regression model reservoir temperatures.
[f] 815,000 af extremely wet year flows with regression model reservoir temperatures.
[g] C.V. = Coefficient of variation for Water Years 1976-1992.

production on average by 17 percent to 2.93 million across the various water-year classes. In comparison with Secretarial Decision flow schedules, potential production also increases by 17 percent to 2.93 million.

Most of the alternatives, including all the water-year class flow regimes, had a constant reservoir release of 450 cfs from September 2 until October 15 and 300 cfs from October 16 until April 21. With the exception of the 140 TAF and the 220 TAF constant flow schedules, this left only the period April 22 to June 9 for variations in flow and water temperature to affect potential production. This considerably narrowed the range of potential production outcomes from the SALMOD evaluations.

Peak potential production for the optimal water temperature of 54° F was obtained with the 647 TAF Normal water-year conditions. Potential production in both numbers and biomass was lowest in the Critically Dry and Extremely Wet water years.

5.6.3.3 Sensitivity to Water Temperatures

Model results from representative individual years for the five water-year class flow regimes are given in Table 5.21. Maximum potential production in terms of both numbers and biomass occurs with spring (March 4 through June 9) water temperatures of 54° F and the next highest potential production occurs at 50° F. All five water-year class flow regimes in combination with a 61° F release gave the minimum potential production (numbers and usually biomass). Potential production values at the best constant spring temperatures of 54° F and the extreme water-year class flow regimes (Critically Dry, Dry, and Extremely Wet) provide less than a 10 percent improvement over the mean production

Table 5.21. Potential production in number (1,000's), mean length (in), and biomass (lbs) of young-of-year chinook salmon from the mainstem Trinity River. The alternatives use 33,000 spawners and either historic flows and temperatures or the flow regimes from the Trinity River Flow Evaluation with BETTER model reservoir release-water temperatures for 1977, 1990, 1989, 1986, and 1983 except for forced constant spring water temperatures.[a]

		Critically Dry	Dry	Normal	Wet	Extremely Wet
Historical Flows and Temperatures	Number Mean Length Weight	1,412 2.49 7,782	2,540 2.39 12,319	2,069 2.42 10,492	2,288 2.35 10,593	637 2.11 2,247
46.4°F	Number Mean Length Biomass	1,313 2.29 5,789	1,994 2.28 8,353	2,137 2.24 8,481	1,351 2.24 5,362	1,270 2.26 5,320
50.0°F	Number Mean Length Biomass	2,216 2.31 10,260	2,643 2.37 12,820	3,239 2.30 14,282	2,647 2.31 11,671	2,296 2.31 10,124
53.6°F	Number Mean Length Biomass	2,561 2.39 12,985	2,733 2.43 14,460	3,494 2.42 17,716	3,085 2.37 14,963	2,695 2.36 13,071
57.2°F	Number Mean Length Biomass	1,583 2.36 7,679	1,607 2.41 8,148	1,753 2.41 8,889	1,783 2.35 8,254	1,779 2.35 8,236
60.8°F	Number Mean Length Biomass	1,215 2.35 5,626	1,313 2.37 6,369	990 2.36 4,802	1,205 2.32 5,578	1,234 2.34 5,712

[a] Beginning weekly reservoir water temperatures were forced to 46.4°, 50.0°, 53.6°, 57.3°, or 60.8° F for the period March 4 to June 17.

values for 33,000 spawners shown in Table 5.20. The Normal and Wet water years with the representative year conditions show 25 percent and 16 percent increases in number of young-of-year, respectively. The calculated biomass is highest for the Normal and Wet water years as well.

For the assumed water temperatures in Table 5.21, potential production in both numbers and biomass was poorest in the Critically Dry and Extremely Wet water years. Normal water year gave the highest potential production in terms of biomass for assumed temperatures of 46°, 50°, 54°, and 57° F. Peak potential production for the optimal water temperature of 54° F was obtained with the 647 TAF Normal water-year conditions. For all three levels of spawning escapement, peak young-of-year potential production was also associated with the 647 TAF Normal water year.

5.6.3.4 Sensitivity to Spawning and Rearing Habitat

The combined effects of doubling spawning, fry rearing, and pre-smolt habitat indicate an increase in mean potential production numbers of 68 percent, whereas halving spawning, fry rearing, and pre-smolt habitat would decrease mean potential production by 52 percent for 68,000 spawners (Table 5.22). Doubling and then halving spawning habitat showed an 11-percent increase and a 25-percent decrease in mean potential production. Doubling fry rearing habitat would increase mean potential production by 31 percent and halving fry rearing habitat would decrease mean potential production by 30 percent . Doubling or halving pre-smolt rearing habitat showed an 8-percent increase and a 10-percent decrease in mean potential production respectively. Note that SALMOD was calibrated to the existing habitat and channel data, and this sensitivity analysis is only an approximation of habitat and channel changes that may result from any rehabilitation strategy. More realistic estimates should be made by calibrating SALMOD to a channel form either as measured after the fact or as predicted by physical process models.

5.6.3.5 Optimizing Potential Production

Additional model runs were made with the goal of examining the potential synergistic and optimizing combined effects of: (1) an increase in spawners from the mean to the maximum number observed in the 17-year historical period (33,000 to 68,000); (2) optimal reservoir release-water temperatures for growth and survivorship (54° F) from the representative years; and (3) an increase in the amount of spawning, fry rearing, and pre-smolt rearing habitat from current conditions to double the current amount (Table 5.23). The highest production was found in the Normal water year, with similar number and biomass production in the paired Dry and Wet water years and in the paired Critically Dry and Extremely Wet water years. Doubling spawning, fry rearing, and pre-smolt rearing habitat resulted in a mean increase in numbers produced of 54 percent. More than doubling the number of spawners resulted in a mean increase of 20 percent. With near optimal temperatures for growth and survivorship, a doubling of production in the Trinity River study area was predicted by simultaneously doubling habitat and the number of spawners (mean increase of 101 percent) (Table 5.23).

> The level of mean production with a combination of optimal temperatures, doubling of habitat, and doubling of spawners is more than triple (327 percent) the mean production calculated with historical flows and temperatures.

5.6.4 Conclusions

For all water-year class flow regimes, the low number of 4,000 spawners severely limits potential production of naturally produced young-of-year chinook salmon (maximum <920,000 outmigrants). With 33,000 spawners, mean potential production increased from 1.9 million with historical flows and temperatures to 2.3 million with the Critically Dry water-year flow regime and 2.6 million with the Normal water-year flow regime (Table 5.20). With the 68,000 spawning escapement, mean potential production increased from 2.2 million with historical flows and temperatures to 2.6 million with the Critically Dry water-year flow regime and 3.1 million with the Normal water-year flow regime. Under existing river-channel conditions with 33,000 spawners and near optimal water-temperature conditions of 54° F, the simulations indicate that potential production can reach 3.5 million pre-smolts with Normal water year of 647 TAF within the existing riparian-bermed channel (Table 5.21).

Model sensitivity runs using the Trinity River Fish and Wildlife Restoration Program's escapement goal of 68,000 naturally produced adult spawners (62,000 fall-run and 6,000 spring-run) and the proposed 647 TAF Normal water-year flow regime indicate that management changes to both rearing and spawning habitat has a major, synergistic payoff that can increase young-of-year chinook salmon production to a mean of 5.2 million (Table 5.22). With a doubling of the current amount of spawning and rearing habitats and near-optimum water temperatures during the spring, potential production reached 5.3 million outmigrants with 33,000 spawners and 7.0 million outmigrants with 68,000 spawners (Table 5.23). The level of mean production (5,856,000)

Table 5.22. SALMOD sensitivity analysis estimates of chinook salmon potential production in the mainstem Trinity study area. The alternatives use 68,000 spawners, regression model water temperatures, and the 647 TAF normal water-year flow regime and doubling or halving existing spawning and rearing habitat.

	Trinity River Study Area Young of Year Outmigrants (1000's)								
	Habitat Remains as Is	Double Spawning Habitat	Halve Spawning Habitat	Double Fry Rearing Habitat	Halve Fry Rearing Habitat	Double Pre-smolt Rearing Habitat	Halve Pre-smolt Rearing Habitat	Double Both Spawning and Rearing Habitat	Halve Both Spawning and Rearing Habitat
Mean	3,124 Base	3,470 +11%	2,341 -25%	4,092 +31%	2,185 -30%	3,361 +8%	2,809 -10%	5,242 +68%	1,637 -52%
Minimum	2,026 Base	2,489 +23%	1,165 -42%	2,612 +29%	1,441 -29%	2,129 +5%	1,859 - 8%	3,640 +80%	857 -58%
Maximum	4,075 Base	4,453 +9%	3,325 -18%	5,130 +26	2,880 -29%	4,681 +15%	3,563 -13%	6,724 +65%	2,215 -46%

Table 5.23. Optimizing potential production in number (1000's), mean length (in.), and biomass (lbs.) of young-of-year chinook salmon from the mainstem Trinity River. All alternatives use 54° F reservoir releases, either 33,000 or 68,000 spawners, and either current habitat conditions or double the habitat for spawning, fry rearing and pre-smolt rearing. Flows and temperature are from the recommended flow regimes from the Trinity River Flow Evaluation with BETTER model reservoir release-water temperatures for 1977, 1990, 1989, 1986, and 1983 except for forced constant spring water temperatures. Beginning weekly reservoir water temperatures were forced to 46.4°, 50.0°, 53.6°, 57.3°, or 60.8° F for the period March 4 to June 17.

Number of Spawners & Habitat	Number Mean Length Weight	Critically Dry	Dry	Normal	Wet	Extremely Wet
33,000 & Current Habitat	Number Mean Length Biomass	2,561 2.39 12,985	2,733 2.43 14,460	3,494 2.42 17,716	3,085 2.37 14,963	2,695 2.36 13,071
33,000 & Double the Habitat	Number Mean Length Biomass	4,062 2.42 21,491	4,217 2.46 22,313	5,339 2.44 28,248	4,620 2.39 22,408	4,228 2.39 20,507
68,000 & Current Habitat	Number Mean Length Biomass	2,941 2.35 14,262	3,319 2.41 16,830	1,229 2.39 20,514	3,810 2.34 17,641	3,182 2.35 14,733
68,000 & Double the Habitat	Number Mean Length Biomass	5,144 2.39 26,083	5,499 2.43 29,097	7,019 2.41 35,591	6,206 2.36 30,102	5,410 2.36 26,239

with a combination of optimal temperatures, doubling of habitat, and doubling of spawners (Table 5.23) is more than triple (327 percent) the mean production calculated with historical flows and temperatures.

Sensitivity-analysis simulations indicate that rearing habitat is severely limiting young-of-year production in the existing channel, and that spawning habitat is limited to a lesser extent (Table 5.22). Although these results are useful and suggest that management efforts and expenditures on increasing rearing habitat versus spawning habitat provide a greater advantage, we caution that SALMOD was calibrated to the existing channel and does not account for habitat effects induced by sediment-flushing or channel-forming events. SALMOD can be most valuable for management when coupled with state-of-the-art models for predicting channel response during annual reservoir operation evaluations.

5.6.5 Recommendations

SALMOD is useful for estimating the relative magnitude of potential production among various flow and temperature regimes. Although the best technology currently available has been used for estimating Trinity River naturally produced young-of-year chinook salmon potential production, appropriate levels of caution and skepticism should be applied to SALMOD output interpretations. The model estimates presented here are not intended to be used as absolute-value predictions of

"Sensitivity-analysis simulations indicate that rearing habitat is severely limiting young-of-year production in the existing channel, and that spawning habitat is limited to a lesser extent."

chinook salmon young-of-year production with a particular regime of flows, water temperatures, and number of spawners. For that reason, percent change (not absolute number differences) from historical flow and water-temperature conditions is a more appropriate index for relative value comparisons of potential production given alternative water-year class flow regimes. In future applications of SALMOD to the Trinity River, the model should be further validated with additional data collected since 1994 and be used to help design and evaluate a rigorous, ongoing biological monitoring program as part of the Adaptive Environment Assessment and Management process. Biological monitoring program data sets most needed are statistically valid estimates of: (1) outmigrant numbers and mean length through time; (2) timing of the peaks of spawning, fry emergence, and outmigration; and (3) density and mean length of fish using various habitat types in the study area through time.

State-of-the-art models for predicting flow regimes, reservoir and river water temperatures, hydraulics, sediment transport, and channel form can be integrated and provided as inputs to SALMOD. The long term, positive effects of sediment-flushing and channel-forming flows should be addressed with a rigorous, ongoing geomorphological monitoring program and models for predicting channel morphology changes. Such a suite of models and complementary monitoring can insure that the best science is provided for annual evaluations of reservoir operations and channel-rehabilitation alternatives aimed toward restoration and maintenance of Trinity River chinook salmon.

State-of-the-art models for predicting flow regimes, reservoir and river water temperatures, hydraulics, sediment transport, and channel form can be integrated and provided as inputs to SALMOD. The long term, positive effects of sediment-flushing and channel-forming flows should be addressed with a rigorous, ongoing geomorphological monitoring program and models for predicting channel morphology changes. Such a suite of models and complementary monitoring can insure that the best science is provided for annual evaluations of reservoir operations and channel-rehabilitation alternatives aimed toward restoration and maintenance of Trinity River chinook salmon.